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Predatory Morphology and Behaviour in *Branchinella occidentalis* (Dakin, 1914) (Branchiopoda: Anostraca: Thamnocephalidae)

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Branchinella occidentalis (Dakin 1914) is redescribed from material collected across the species natural distribution, with special attention to its functional morphology in relation to predatory feeding behaviour observed in the wild and in culture. We present *B. occidentalis* as a predatory anostracan with physical adaptations convergent with other large predatory anostracan taxa. Comparisons with its closest sister taxon, *B. australiensis* (Richters 1876), and with other predatory species are made and discussed. Revised and updated definitions and diagnoses for the Thamnocephalidae, *Branchinella*, and *Branchinella* sensu stricto are provided.

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Key Words: Australia, *Branchinella australiensis*, *Branchinecta*, fairy shrimp, predators.

INTRODUCTION

Despite being a widespread and common component of the Australian anostracan fauna (Rogers and Timms 2014), *Branchinella occidentalis* Dakin 1914 is not well characterised. Dakin (1914) described it as a variety of *Branchinella australiensis*, but Linder (1941) redescribed it as a separate species, a position maintained by Geddes (1981), Timms (2002), and Rogers (2013). However, these authors did not realise it was predatory, so that any adaptations for this mode of life went unnoticed. We present direct evidence that this species is predatory and describe some of the functional morphology related to its predatory behaviour. Given that the North American *Branchinecta gigas* Lynch 1937 and *B. raptor* Rogers et al. 2006 (Branchinectidae) display many adaptations enabling them to be successful predators (Fryer et al. 1966; White et al. 1969; Rogers et al. 2006), it is of interest to study *Branchinella occidentalis* in detail, it being a member of a different family and living on a different continent.

MATERIALS AND METHODS

Specimens were collected from the wild by dip net in inundated pools, or substrate samples were collected from dry pools and adults were cultured in the laboratory. Captured and cultured adults were preserved in 90% ethyl alcohol. After 24 hours the preservative was replaced with 70% ethyl alcohol to prevent softening or decomposition (Rogers 2002).

Laboratory cultures were run as follows: substrate containing eggs was collected from the deepest portion of pools that supported *B. occidentalis*. This substrate was placed in black plastic tubs (60cm length x 45cm width x 15cm depth, 27L volume), with each pool sample in its own tub. The tubs were filled half full with 20°C deionized tap water. The culture was gently mixed and then given rapid aeration via an air stone. The aeration was reduced to a gentle bubbling (not creating any currents or foam) after two hours. After 24 hours the culture tub was filled to capacity with 20°C deionized tap water and incubated at 20°C.

PREDATORY FEATURES IN *BRANCHINELLA OCCIDENTALIS*

After 24 hours the cultures were treated with 5ml of powdered aquarium fish vegetable flake food and 0.5 ml of brewers' yeast suspended in 10ml of water from the culture. The cultures were fed the same again when naupliar larvae were visible in the tubs and then fed the same way every three to five days, but without the yeast. Notostracans were removed from the cultures as they were observed, as they are anostracan predators. Adult *B. occidentalis* eventually reached maturity and consumed all other nonconspicuous anostracans in the culture. Other anostracans from other cultures were offered as food (*Artemia franciscana* Kellogg, 1906, *Branchinecta lindahl* Packard, 1883) and were readily taken.

Digestive tracts were dissected from fifteen specimens from five locations and the gut contents were examined.

Specimens were observed and dissected under a Wild M-5 binocular dissection microscope. Drawings were made by hand.

Material was collected and examined from various populations across Australia within the known range of the species (Fig. 1). The following abbreviations are used here: "DCR" refers to collection accession numbers in the first author's collections, "BVT" for the second. AM = Australian Museum; SAM= South Australia Museum; WAM= Western Australia Museum; CNP= Currawinya National Park.

A total of 314 *B. occidentalis* specimens were

examined in this study (see Material Examined section below). In addition, the following material was examined for comparison:

Branchinella australiensis (Richters, 1876)

AUSTRALIA: NEW SOUTH WALES:

Steve's Pool, Muella Station; two males, two females; June 1999; B. V. Timms, DCR-269.
Sue's Pan, Bloodwood Station, 29° 29' 05.60"S, 144° 48' 38.00"E; 5 males, 8 females; August 2015; BVT and DCR.

Branchinecta gigas Lynch, 1937

CANADA: ALBERTA:

Chain Lakes; one male, one female; 29 May 1965; G. White, Det. DCR, DCR-223.

USA: CALIFORNIA:

Modoc County: Middle Alkali Lake, at HWY 299 causeway; four males, four females; March 1993; S. Cepello, DCR, DCR-15.

Siskiyou County:

Pool east of intersection of Highway 97 and Highway 161, on north side of Indian Tom Lake; 21 males, 33 females; 27 March 1998; DCR, R.E. Hill, DCR-127.

Pool east of intersection of Highway 97 and Highway 161, on north side of Indian Tom Lake; ten males, ten females; 18 April 2003, DCR, C.L. Rogers, S. Wile, DCR-542.

Branchinecta raptor Rogers et al., 2006

USA: IDAHO:

Ada County:

Orchard Training Area, Armadillo Playa; one male, one female; 18 March 2004, L. Evans, D. Quinney, J. Weaver, Det. D. C. Rogers, DCR-604.

Orchard Training Area, Tadpole Lake; four males, four females; 18 March 2004; L. Evans, D. Quinney, J. Weaver, Det. D. C. Rogers, DCR-605.

Orchard Training Area, Armadillo Playa; five males, five females; 31 March 2004, L. Evans, D. Quinney, J. Weaver, Det. D. C. Rogers, DCR-606.



Figure 1. Distribution of *Branchinella occidentalis* based upon Geddes (1981) and Rogers and Timms (2014) and records presented here.

RESULTS

Thamnocephalidae Packard, 1883 (sensu Rogers, 2006)

Diagnosis.— (revised from Rogers, 2006) Gonopods close set, basal portions soft or rigid, with one or more longitudinal rows of spines. Eversible portion typically becoming explanate distally. Vas deferens looped dorsally. Seminal vesicles absent. Frontal appendage present or absent. Second antennae never fused, separated by labrum, with distal antennomeres curving medially or posteriorly. Antennal appendages present or absent. Second maxillae with one or two apical setae or spines. Eleven pairs of thoracopods, each bearing a single praepodite. Adults range in length from 6 to 60mm. Two subfamilies, seven genera, ~70 species total, reported from all continents except Antarctica.

Comments.— Previous descriptions of the family have defined it in part as having maxilla II bearing a single apical seta. Below, we found that in *B. occidentalis* the maxilla II possesses two apical spines.

Branchinella Sayce, 1902

Diagnosis.— (revised from Rogers, 2006) Fully extended gonopods reaching to abdominal segment III, IV or V. Gonopods may be entirely retractile, or bearing short, rigid, tubular chitinated basal portions, which may each bear a single ventrolateral tubercle. Gonopod rigid basal portion without medial patch of spines. Gonopod distal eversible portion soft, expanded in distal third; lateral surface bearing one or more longitudinal rows of large, dense, spines; medial surface with large, small or a mixture of scattered spines sometimes in short rows. Gonopod apex truncated with a small, centered conical projection, directed distally. Brood pouch expanded proximally, narrowing abruptly to a subcylindrical structure, extending to base of abdominal segment IV, V, VI or VII. Males frontal appendage and/or antennal appendages present or absent. Male second antenna depending from head anterioventrally, slightly coalesced at base, but otherwise free. Second antenna distal antennomere arcuate or angled. Female second antennae lamellar, with truncated or slightly acute apices. Resting eggs variable. *Branchinella australiensis* is the type species of the genus by monotypy. Two subgenera: *Branchinella* sensu stricto, limited to Australia, and *Branchinellites* from Eurasia and Africa.

Branchinella (sensu stricto) Rogers, 2006

Diagnosis.— (revised from Rogers 2006) Gonopod eversible portion with posteriolateral surface bearing a single, longitudinal row of large, posteriorly directed

papilliform spines. Gonopod eversible portion with distal portion with various arrangements of scattered or rows of small spines. Male frontal appendage present or absent, if present, form highly variable. Antenna like appendage absent. Resting eggs variable, usually with variously irregular polygons to moderately spinose.

Branchinella occidentalis (Dakin, 1914)
(Figure 1, 2)

Branchinella australiensis var. *occidentalis* Dakin 1914

Branchinella occidentalis (Dakin 1914) fide Linder 1941; Geddes 1981; Rogers 2006, 2013; Timms and Lindsay 2011.

Branchinella parooensis Henry 1924

Branchinella parooensis (Henry 1924)

Diagnosis.— Length 22–50mm from frons anterior margin to telson posterior margin. Compound eye peduncle extremely short. Compound eye reduced. First antenna greatly elongated, whip like, two to six times as long as second antenna. Frons and anterior surface of antennae II broadened laterally.

Type Material.— Western Australian Museum, Perth, Australia: Syntypes, 5 km SE of Wiluna, 26° 31' 58"S, 120° 40' 1"E, 2 males, unknown collector, 1911, WAM 157, 158. One male is dissected.

Type Locality.— Australia: Western Australia: Wiluna: Lake Violet.

Material Examined.— In addition to the syntype material, the following specimens were examined:

NEW SOUTH WALES:

Paroo, Bloodwood Station, 11.5 km NW of homestead, Sues clay pan, 29° 33' 21.7"S, 144° 50' 14.4"E; 5 males, 9 females; 1 June 1999; BVT, DCR-267.

Same site; 6 males, 9 females, 6 February, 2007; BVT; AM P99164.

Same site; 4 males, 6 females; 25 July 2015; BVT and DCR.

Paroo, Bloodwood Station, 8.9 km W of Homestead, Plover pan, 29° 31' 1.2"S, 144° 49' 39.9"E; 5 specimens; 9 June 1998; BVT; AM P99161.

Same site; 12 males, 5 females; 26 July 2015; BVT and DCR.

Paroo, Bloodwood Station, 9.8 km WSW of homestead, Melaleuca Pan, 29° 33' 02.4"S, 144° 49' 07.6"E; 8 males, 3 females; 25 July 2015; BVT and DCR.

PREDATORY FEATURES IN *BRANCHINELLA OCCIDENTALIS*

Paroo, Bloodwood Station, 8.6 km SW of homestead, Turkey pan, 29° 33' 21.7"S, 144° 50' 14.4"E; 19 February 2010; B.V. Timms, AM P99162.

Same site; 1 June 2016; AM P99163.

Paroo, Bloodwood Station, 9.3 km NW of homestead, the freshwater lake; 11 males, 14 females; July 1997, BVT, DCR-477.

Paroo, 130 km NW of Bourke, roadside pool at Yantabulla, 29° 19' 36.7"S, 145° 00' 11.2"E; 26 males, 31 females; 6 July 2001, BVT, DCR-357.

Paroo, Goorimpa Station, a clay pan, 30° 20'S, 144° 01'E; 1 male; November 1923; M. Henry; AM P6774.

NORTHERN TERRITORY:

Alice Springs area, Illpara clay pan, Alice Springs, 23° 45' 16.5"E, 133° 47' 51.5"E; 2 specimens; 30 March 2012; G. McBurnie; AM P99151.

QUEENSLAND:

CNP, 40 km NE of Hungerford, a clay pan, 28° 44' 0.3"S, 144° 41' 27.5"E; 8 specimens; 8 June 2007; BVT; AM P.99154.

CNP, 17.3 km NNE of Hungerford, a clay pan, 28° 50' 41.0"S, 144° 26' 58.1"E; 1 September 1996, BVT; AM P99155.

CNP, 2.3 km N of Lake Karatta, a clay pan, 28° 52' 20.2"S, 144° 17' 34.7"E; 23 specimens; 2 July 1993; BVT; AM P99156.

CNP, North Kaponyee Lake, 28° 49' 12.5"S, 144° 19' 21.3"E; 4 specimens; 13 July 1998; BVT; AM P99157.

CNP, South Kaponyee Lake, 28° 51' 27.5"S, 144° 20' 6.0"E; 4 specimens; 13 March 1997; BVT; AM P99158.

Paroo, Rockwell Station, 1.7 km N of Lake Bulla, a clay pan, 28° 52' 59.4"S, 144° 55' 57.4"E; 9 specimens; 9 June 2007; BVT; AM P99159.

Paroo, Rockwell Station, 5.4 km N of Lake Bulla, a clay pan, 28° 51' 4.4"S, 144° 56' 51.1"E; 53 specimens; 10 June 2007; BVT; AM P99160.

SOUTH AUSTRALIA:

Oodnadatta Track, 60 km N of Oodnadatta, Fogartys clay pan, 27° 03' 21.4"S, 135° 14' 57.2"E; 10 specimens; 11 March 2011; BVT and M. Schwentner; AM P99152.

Oodnadatta Track, 16 km N of William Ck. Pub, a clay pan, 28° 52' 3.6"S, 136° 11' 8.6"E; 13 specimens; 12 March 2011; BVT and M. Schwentner; AM P99153.

91 km S of William Ck. Pub, a clay pan, 29° 43'S, 136° 19'E, 2 specimens; 5 December 1974, SAM C6051.

WESTERN AUSTRALIA:

North of Murchison River, Gee Gie Outcrop, south end, 27° 21'S, 114° 08'E; 2 specimens; 28 November 1968; Kidner Loveland; WAM 12484.

North of Murchison River, Lake Culcurdoo, 27° 25'S, 114° 08'E; 1 specimen; 27 November 1968; Kidner Loveland; WAM 12499.

Paynes Find, 12 km S, a clay pan, 29° 19' 52.3"S, 117° 47' 23.3"E; 6 August 2004; 12 males, 10 females; BVT; DCR - 632.

Same site; 8 specimens; 21 August 2011; BVT; AM P 99149.

Ora Banda, Rowles Lagoon, 30° 25' 38.5"S, 120° 51' 49.7"E; 2 specimens; 10 March 2014; K. Quinlan and J Jackson; WAM 59072.

Kalgoorlie, 12.7 km SSW, Lake Hannan, 30° 51' 0"S, 121° 31' 58"E; 2 specimens; 17 March 1937; D. Serventy; WAM 12459.

Norseman-Lake King Road, 4.5 km N, a clay pan, 32° 39' 10.8"S, 120° 47' 8.6"E; 7 specimens; BVT; AM P99150.

Description.— Length 22 – 50mm from frons anterior margin to telson posterior margin.

Male. Head (Fig. 2A) broad, dorsoventrally flattened, frons projecting over bases of compound eyes. Dorsal organ reduced. Compound eye reduced, peduncle short, subequal in length to compound eye diameter. Naupliar eye small, deep below integument. Frontal appendage barely discernable; at most a pair of low, rounded protrusions.

Antenna I elongate, 2.0 to 6.0 times the length of antenna II. Base broad, 0.8 times width of antenna II base.

Antenna II of two articles. Proximal antennomere subcylindrical, medial surface proximal half with a low, ill defined, longitudinal ridge. Distal antennomere arcuate approximately at half its length, 1.4 times as long as proximal antennomere, tapering from a broad base to a narrow apex. Base ~0.8 times as wide as proximal antennomere distal end.

Labrum rounded transversely, projecting posteriorly over mouthparts to maxillary gland. Posterior portion tessellated with transverse chitinated microridges. Labral projection smooth, with acute apex bending posteroventrally.

Mandible (Fig. 2C) surface with a small anterior incisor, subtended anteriolaterally by a small setal tuft. Mandible medial margin with a broadly spaced row of small denticles; grinding surface generally smooth, covered in fine denticles. Maxillary glands large, overlapping mandible base, broader distally than proximally. Maxillary gland duct opening at base of Maxilla I.

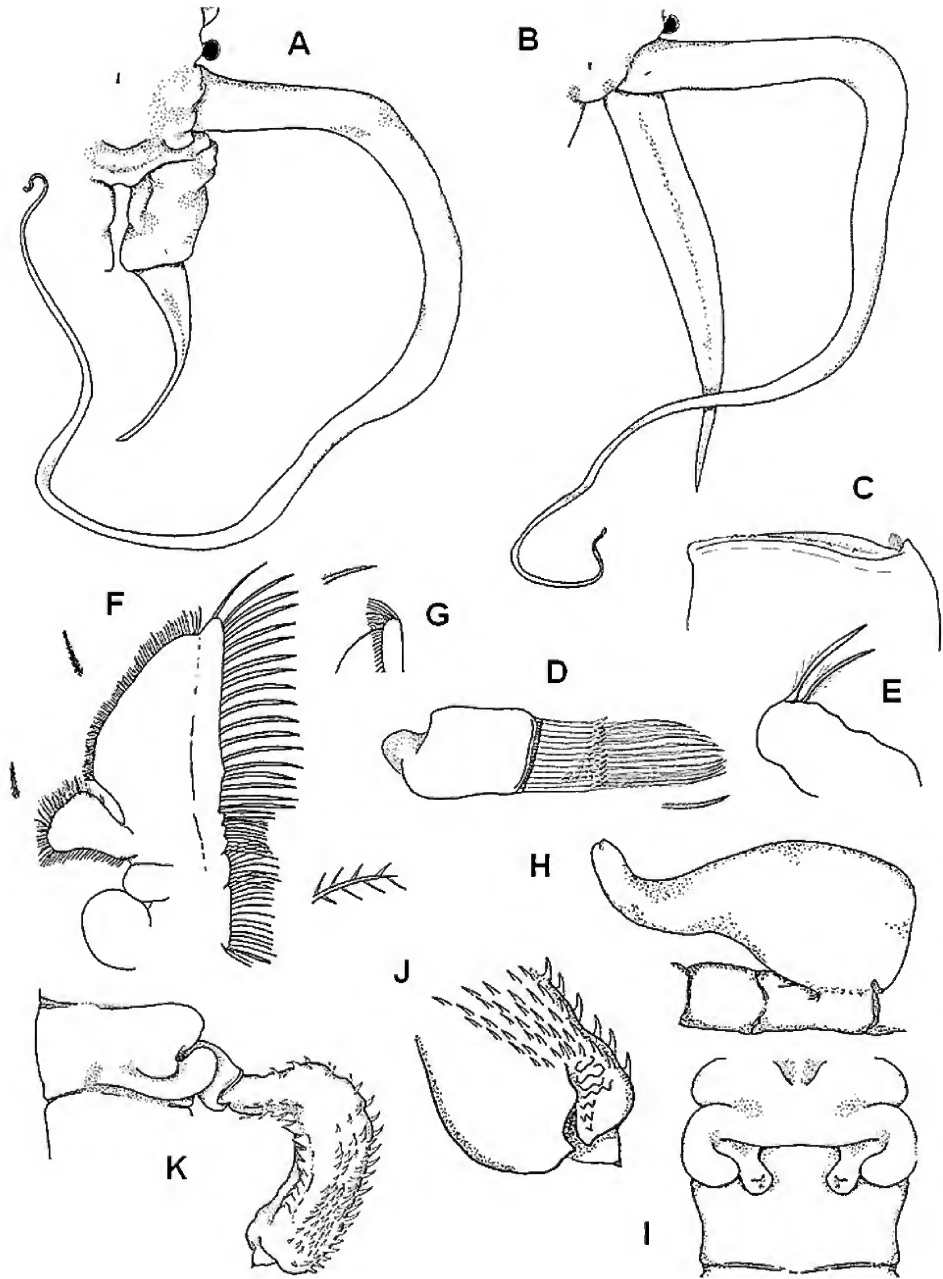


Figure 2. *Branchinella occidentalis*. A) Male, head, left half, anterior view; B) female, head, left half, anterior view; C) mandible, posteriomedial view; D) maxilla I, posteriomedial view; E) maxilla II, lateral view; F) thoracopod V, right side, posterior view, with inset details of seta or spine apices; G) thoracopod V, right side, distal end, posterior view, with medial margin folded back; H) brood pouch, left lateral view; I) male genital segments (abdominal segment XII + XIII) with retracted gonopods, ventral view; J) everted right gonopod apex, medial view; K) everted right gonopod, lateral view.

PREDATORY FEATURES IN *BRANCHINELLA OCCIDENTALIS*

Maxilla I (Fig. 2D) of two articles. Proximal article a short, subcylindrical peduncle. Distal article broadly rectangular, distal margin fringed with a close set row of stout setae. Setae composed of two portions: proximal portion stout, rigid, and with a distal spine. Posterior most setae, except ultimate and penultimate, bearing one to four subdistal rounded spines. Setal distal portions, soft, flexible, and pectinate. Posterior most setae longer than anterior most setae.

Maxilla II (Fig. 2E) lobiform, with two distal spines, each plumose proximally.

Thoracic segments smooth, unadorned. Feeding groove absent, ventral surface flat, broad.

Thoracopods serially homologous and elongated. Thoracopod V (Fig. 2F) with endites lamellar. Endite I+II oblong, medial edge straight, margined with elongate setae bearing numerous spinulae, spinulae separated by at least their length. Seta length subequal to endite I+II breadth.

Endite III rounded, ~0.5 times the breadth of endite I+II, margined with elongate setae bearing numerous spinulae, each separated by a distance at least equal to their length. Seta length subequal to endite I+II breadth.

Endites IV, V, and VI rounded, each ~0.5 times the width of endite III, margined with elongate setae bearing numerous spinulae, each separated by a distance at least equal to their length. Seta length subequal to endite I+II breadth.

Endopod medial margin plus all endites as one body articulate, bending posteriorly, and capable of lying flat against limb posterior surface (Fig. 2G).

Endopod broadly triangular, distomedial corner projecting ventrally. Endopod mesal edge and projecting distomedial corner margined with stout, aciculate, bipectinate spines. Spines vary in length among individuals from one half to subequal the breadth of the endopod. Endopod ventrolateral edge margined with short setae, covered in fine setulae. Each seta ~0.2 times the length of the endopod medial spines.

Exopod, lamellar, distally explanate ovate, with rounded corners, generally margined with short setae, covered in fine setulae. Each seta ~0.2 times the length of the endopod medial spines. Ventral margin with some setae set back from margin on both anterior and posterior surfaces.

Epipodite a short, rounded lobe, inerm. Praeepipodite broadly circular, inerm.

First genital segment (thoracic segment XII) (Fig. 2I, K) tumid, with several ventral folds, overlapping gonopod bases anteriorly, and laying over base of second genital segment (thoracic segment XIII) on lateral sides of gonopods.

Gonopod basal portions (Fig. 1) close set to medial line, subcylindrical, smooth, arcing medioventrally. Gonopod distal portions (Fig. 2K) arcing posteriomedially, extending posteriorly to abdominal segment II or III, with apex explanate and truncated. Anterior, lateral and medial surfaces with confused longitudinal rows or recurved spines, becoming more confused distally. Distal most spines becoming nearly straight, subcylindrical, and one fourth shorter than more anterior spines. Gonopod posteriolateral surface with a longitudinal row of broad, triangular, lamellar, papillae, each tipped with a short, rounded chitinated spine. Gonopod apex (Fig. 2J) with a conical papilla, tipped with a small rounded spine. Gonopore opening in a subapical narrow slit, positioned medially and opening subapically at the base of the apical, conical papilla.

Abdominal segments and telson subcylindrical, smooth, unadorned.

Cercopods long tapering cones, apically subacute, subequal in length to the last two abdominal segments plus telson. Each cercopod with medial and lateral margins fringed with long, plumose setae.

Female. Head (Fig. 2B), eye and antenna I as in male. Antenna I length ~2.3 times antenna II length, with basal width equal to antenna II basal width. Antenna II broadly lamellar, tapering to an acute apex. Mouth parts, thorax and thoracopods as in male.

First genital segment (thoracic segment XII) smooth. Brood pouch (Fig. 2H) subconical, tapering posteriodistally to simple gonopore, directed posteroventrally. Gonopore posterior lip projecting distally, subacute.

Abdomen, telson and cercopods as in male.

Egg.— (After Timms & Lindsay 2011) Diameter ~500 µm. Average size 492.2 µm. Surface with numerous polygons. Polygonal depressions fewer and shallower in western populations than eastern. Polygonal depressions with steep walled ridges crested with a fringe of short spines. Ridge walls with scattered pores. Polygonal depressions with floors flat and dimpled or markedly concave.

Distribution and Habitat.— *Branchinella occidentalis* is widespread across arid Australia in the Western and Eastern Australian Anostracan Bioregions (Fig. 1) (Rogers & Timms 2014). Habitat is general deep and turbid, with some level of substrate salinity and carbonate present and with acid sulfates present or not (Rogers & Timms 2014). Localities for this species are in calcarosol, dermosol, hydrosol, kurosol, sodosol, tenosol, and vertisol soils (Rogers & Timms 2014).

Branchinella occidentalis is known from 42 locations (Rogers & Timms 2014) and is found co-occurring with *Branchinella lyrifera* Linder 1941 (21.4% of records), *B. affinis* Linder 1941 (11.9%), and *B. australiensis* (9.5%). It also co-occurs with *B. proboscida* Henry 1924, *B. pinnata* Geddes 1981, *B. halsei* Timms 2002, *B. budjiti* Timms 2001, *B. frondosa* Henry 1924, and *Streptocephalus archeri* (Sars 1896), (all <7%); however the one, two, or three records for each of these species were always occurrences with one or more of the primary three co-occurring species. *Branchinella occidentalis* was found on five occasions to be the only active resident of the pool (11.9%).

Behaviour.— Nine specimens of large adult, field collected, preserved *B. occidentalis* material from various locations were found with *B. lyrifera* or *B. affinis* protruding at various distances from the mandibles. In culture, large adult *B. occidentalis* were observed to consume live *B. lyrifera*, *B. affinis*, and *B. frondosa* as well as cladocerans that hatched in the same culture, as were *Artemia* sp. and *Branchinecta* sp. that were offered to them. Dead or moribund specimens were ignored.

Predatory behaviour was only ever observed in animals greater than 5cm in length, and only towards anostracans that were 2cm in length or smaller.

Capture was observed several times: the larger *B. occidentalis* detected the smaller anostracan between it and the culture tub wall or the substrate. The *B. occidentalis* rolled over with its venter to the substrate and pressed down over the prey item, occasionally arcing its body. Eventually, the *B. occidentalis* came away from the substrate with the prey item in its jaws.

Prey always appeared to be identified by tactile and not visual detection. Prey was always consumed abdomen first. Specific manipulation of the prey was not clearly observed. However, the limbs were directly involved in pinning the prey, orienting it with the abdomen towards the mandibles, and moving it towards the mandibles.

Only one prey item at a time was ever observed in the jaws of any one *B. occidentalis*. Prey was never observed to be carried for later consumption as in *Branchinecta raptor* (Rogers et al. 2006). When prey items were not available, filamentous green algae and periphyton were consumed.

Gut contents.— Only *B. occidentalis* specimens greater than 5cm in body length had macrometazoans in the gut. All specimens examined had micrometazoans, algae, diatoms, detritus, chironomid midge larvae, and

clay particles. Both male and female *B. occidentalis* had the remains of anostracans in the gut. One specimen from Yantabulla also had cladocerans (unidentifiable to family) present in the gut.

DISCUSSION

Branchinella occidentalis is presented here as a large predatory anostracan. Direct observations demonstrate that it is predatory on smaller anostracans and occasionally cladocerans as a large adult, but that it still will filter feed and scrape periphyton.

The modified thoracopods of *B. occidentalis* provide a limited degree of dexterity for the manipulation of prey, but not anywhere near the dexterity level observed in *B. raptor* or *B. gigas* (Rogers et al. 2006). The various other hunting methods and postures observed in the predatory *Branchinecta* species (White et al. 1969; Rogers et al. 2006) were never observed in *B. occidentalis*, and it may be that this species is less specialised than the other species.

Dakin (1914) figured the fourth limb (with no real description of it), but the limb appears to be from a juvenile individual. The differences between Dakin's (1914) limb and limbs in our adult material suggest that a serial study of the development of the limbs and mouthparts may demonstrate that this species changes feeding modes over time, as was reported for *B. gigas* and *B. ferox* (Milne-Edwards 1840) (sensu Petkovski, 1991) (Daborn 1975). Dakin's (1914) only real comment on the limbs was their superficial similarity with those of *B. australiensis*.

Geddes (1981) provided a very brief redescription of *B. occidentalis*, but did not note the folding adaptation of the limb medial margin. Geddes (1981) did comment on the modified head and eyes and strangely stated that the modifications were analogous to the condition in *Dendrocephalus* (no citation provided): however, no such modifications of the head or eyes exist in that genus.

Geddes (1981) depicts the mouthparts for *B. australiensis*. Both in Geddes study and in our own we found that labrum, maxilla I and II, are nearly identical to those in *B. occidentalis*; however in *B. australiensis* the maxilla II spines are widely separated.

The morphology and behaviour of *B. occidentalis* is convergent with that of the largest two species of *Branchinecta*, both of which are known predators (Fryer 1966; Rogers et al. 2006). Specifically, the abnormally large size, reduced eyes, elongated first and/or second antennae, and modified mouthparts are convergent with the two *Branchinecta* species.

PREDATORY FEATURES IN *BRANCHINELLA OCCIDENTALIS*

Granted, not all these characters are modified in the same manner, but they are modified to support a predatory lifestyle. The limb modifications are very different; in *B. raptor* and *B. gigas* endites I and II are not fused (as in all other anostracans), and the endites and the endopod medial margin are not articulated (Rogers et al. 2006). Rather the endites in these two species are modified for gripping and the endopod for grappling (Rogers et al. 2006).

Our study demonstrates that a predatory lifestyle in the Anostraca has evolved more than once and in more than one family. It remains to be seen if *B. australiensis* is also actively predatory.

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Précis of Palaeozoic Palaeontology in the Southern Tablelands Region of New South Wales

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Percival, I.G. and Zhen, Y.Y. (2017). Précis of Palaeozoic palaeontology in the Southern Tablelands region of New South Wales. *Proceedings of the Linnean Society of New South Wales* **139**, 9-56.

This compilation of all known palaeontological data from Lower Ordovician to Upper Devonian rocks exposed in the Boorowa–Crookwell–Taralga–Yass–Goulburn–Braidwood region of southeastern New South Wales, draws on a voluminous scientific literature of more than 270 papers and reports. Within this region are some of the most famous and intensively studied fossiliferous localities in the state, particularly in the Yass–Taemas area. Revised faunal lists provide the basis for new or refined age determinations, resulting in improved biostratigraphic correlation amongst the 64 formations and their members that yield fossils in the region. Early Silurian (early Wenlock) conodonts found in allochthonous limestones of the Hawkins Volcanics, the lowermost unit of the Yass Basin succession, are documented, as are representative conodonts from allochthonous limestone of late Silurian (Ludlow) age previously erroneously assigned to the early Silurian (late Llandovery) Jerrawa Formation. A new species of the coniform conodont *Panderodus* is described under open nomenclature. It is recommended that the name Hanaminno Limestone be suppressed.

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KEYWORDS: Biostratigraphy, Conodonts, Devonian, Graptolites, Ordovician, Palaeontology, Silurian.

INTRODUCTION

Palaeozoic strata exposed in the Boorowa–Crookwell–Taralga–Yass–Goulburn–Braidwood region of southeastern New South Wales (Fig. 1) range in age from Early Ordovician to Late Devonian (Fig. 2) and include, in the Yass–Taemas area, some of the most famous fossiliferous localities in New South Wales. This compilation of all known palaeontological information from these rocks draws on a voluminous scientific literature including more than 270 papers and reports (approximately 15% of which have been published in the *Proceedings of the Linnean Society of New South Wales*) in which Palaeozoic fossils from the region have been documented. The region falls largely within the confines of the Goulburn 1:250,000 and Braidwood 1:100,000 mapsheets that have recently been investigated and remapped by the Geological Survey of NSW (GSNSW), but palaeontological data from adjacent mapsheets is also utilised to provide

age constraints. However, unpublished works, such as student theses, are largely excluded to avoid the possibility of introducing nomina nuda or clouding the record with identifications that have not been peer-reviewed. Although some parts of the present paper were incorporated into the Palaeontological Appendix (published on DVD) for the Goulburn Geological Sheet Explanatory Notes (Percival 2012b, in Thomas and Pogson 2012), several identifications and some correlations proposed therein have been revised for this expanded review, which also incorporates previously unpublished data and fossil determinations from the Braidwood region (Fitzherbert in press).

Previous palaeontological studies in the Southern Tablelands region have been concentrated in two highly fossiliferous areas: (1) the Silurian to earliest Devonian succession of the Yass Basin, and (2) the carbonate-dominated Murrumbidgee Group (of Early Devonian age) surrounding Burrinjuck Reservoir. Additional research has focussed on faunas of the

PALAEOZOIC PALAEOLOGY OF SOUTHERN TABLELANDS NSW

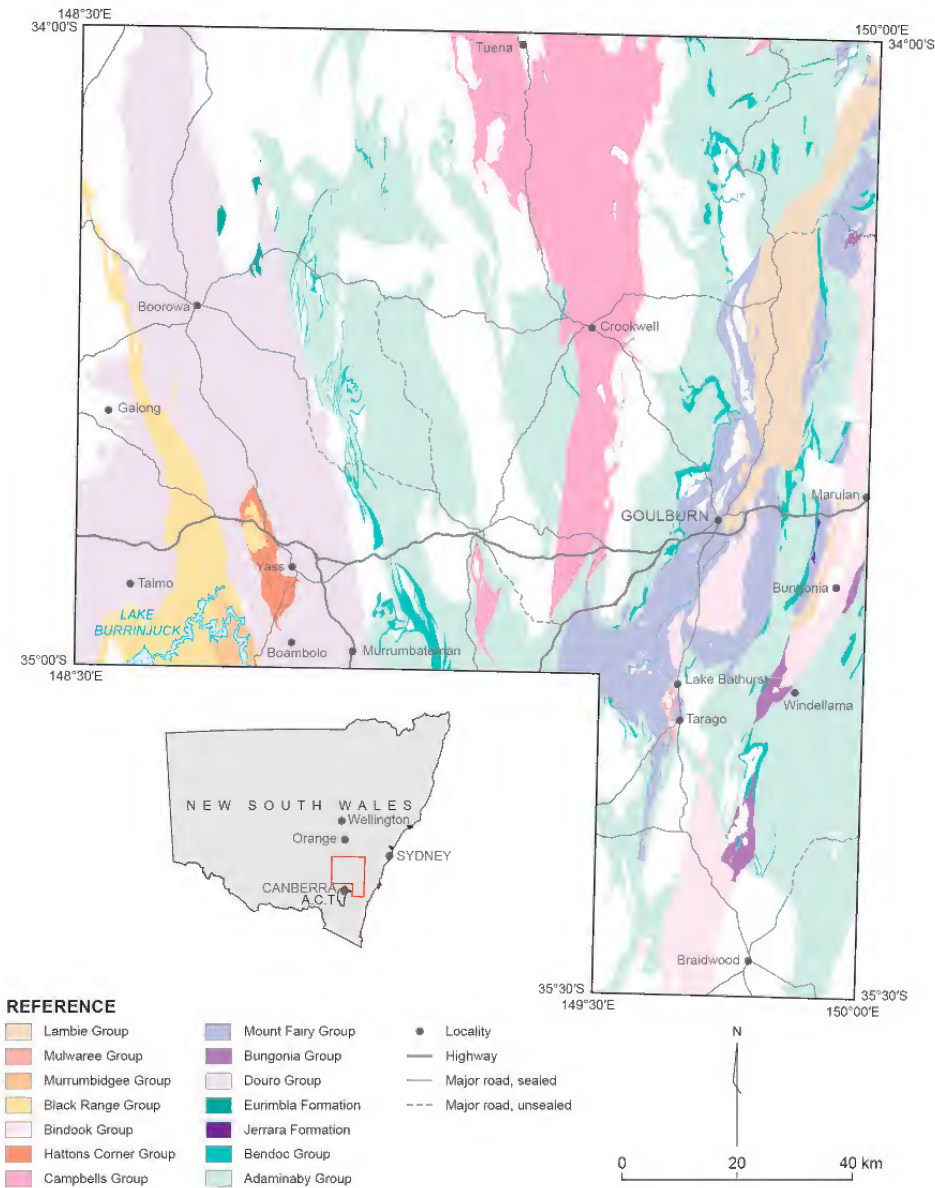


Figure 1. Map of the Southern Tablelands region of southeastern New South Wales, showing the main localities mentioned in the text. Simplified geology, including sedimentary groups referred to in the text, is adapted from the Goulburn 1:250,000 Geological Sheet, Second Edition (Thomas et al. 2013) and the preliminary Second Edition of the Braidwood 1:100,000 Geological Sheet (Fitzherbert et al. 2011). Un-coloured areas are unfossiliferous rocks, predominantly granites.

Early Devonian Windellama Limestone Member of the Tangerang Formation, on Late Ordovician graptolites in the Bendoc Group, and conodont biostratigraphy of cherts in the Early to Middle Ordovician Adaminaby Group.

ORDOVICIAN STRATIGRAPHY AND BIOSTRATIGRAPHY

Adaminaby Group

Abercrombie Formation (0aa on Fig. 2)

The Abercrombie Formation ranges in age from the Early Ordovician (?late Tremadocian to Floian, equivalent to Bendigonian) to the earliest Late Ordovician (Sandbian, or early Gisbornian) (Fig. 2). This latter age is relatively well-constrained, the maximum age less so, with almost all biostratigraphic data being derived from conodonts and other microfauna preserved in cherts (Percival 2012a). Recent mapping of the Abercrombie Formation on the Goulburn 1:250,000 mapsheet has resulted in recognition of several new chert-dominated members (Thomas and Pogson 2012). A summary of the lithostratigraphy of this formation and its constituents is given in Percival et al. (2011).

Unnamed cherts in lowermost Abercrombie Formation

A few very thin and discontinuous chert beds interbedded in a shale-dominated section beneath the Mummel Chert Member are characterised by the presence of *Paracordylodus gracilis* and the absence of *Oepikodus evae*. This suggests an age range for the lowermost Abercrombie Formation of late Tremadoc to early Floian (early Bendigonian).

Mummel Chert Member (0aam on Fig. 2)

Conodonts commonly observed in thick sections of cherts from the Mummel Chert Member include *Oepikodus evae* (often abundant), *Paracordylodus gracilis*, *Periodon flabellum*, *Acodus* sp., *Drepanodus arcuatus*, and other coniform elements probably assignable to *Drepanoistodus*. *Bergstroemognathus extensus* is a rare but distinctive associate, *Microzarkodina* (species indeterminate) is equally uncommon, and one element possibly referable to *Fahraeusodus marathonsensis* was observed. Where *O. evae* is present (e.g. Percival et al. 2003:fig. 1.19, 21-22; Percival et al. 2011:photograph 1; Percival 2012a:fig. 3F), the age of this assemblage could potentially span the range of the eponymous zone, i.e. late Bendigonian (Be3-4) to early Castlemainian

(top Ca1). Co-occurrence of *Oepikodus evae* and *Paracordylodus gracilis* restricts the possible age range of some chert horizons to the late Bendigonian (Be3-4). An unusual assemblage identified in one chert sample comprised *Cooperignathus* cf. *C. aranda*, *Prioniodon* sp., and *Periodon flabellum*, together with various coniform elements including *Drepanodus*. Murray and Stewart (2001) incorrectly attributed a Darriwilian-Gisbornian age to this horizon (their locality R16472) on the basis of a mis-identified *Pygodus*.

Remains of sponges preserved in siliceous siltstones grading to spiculites within the Mummel Chert Member are mostly in the form of disaggregated spicules. However, in one sample from the Braidwood mapsheet, two different whole sponges are present. One of these, visible in transverse section across the cylindrical sponge body, shows remarkably well-preserved nail-head spicules characteristic of lithistid demosponges (Percival 2012a:fig. 3L).

Unnamed cherts in middle Abercrombie Formation (0aac on Fig. 2)

Most occurrences of the distinctive conodont *Spinodus spinatus* are in cherts from within the undifferentiated middle part of the Abercrombie Formation (Thomas and Pogson 2012). Typical coniform elements co-occurring in these cherts include *Paroistodus venustus*, *Protopanderodus* sp., *Drepanoistodus* sp. and “*Drepanodus*” sp. Rarer associates include *Periodon macrodentata*?, *Baltoniodus* sp., *Protoprioniodus simplicissimus*, and *Ansella*? sp. Cherts containing this assemblage are most likely of early Darriwilian (Da1?-2) age, although *Spinodus spinatus* has a longer range, extending into the Late Ordovician. For example, in one sample (interpreted to be of Da3 age) from the Goulburn 1:250,000 mapsheet, *S. spinatus* occurs with fragmentary *Histiodela* together with a probable *Paroistodus horridus* element.

Jenkins (1982b) documented a diverse graptolite fauna from black mudstone interbedded with turbiditic sandstone near the crossing of the Kings Highway over the Mongarlowe River, 15 km east of Braidwood. Species recognised include *Didymograptus cognatus*, *Tetragraptus* sp., *Isograptus* sp., *Glossograptus acanthus*, *Glossograptus* sp., *Paraglossograptus* cf. *tentaculatus*, *Apiograptus*? *crudus*, *Cryptograptus inutilis*, *Glyptograptus intersitus*, *Pseudoclimacograptus differtus* and *Diplograptus*? *decoratus*, together with a lingulate brachiopod. Jenkins deduced an age close to the boundary of the Da2 and Da3 zones for this fauna.

PALAEOZOIC PALAEOONTOLOGY OF SOUTHERN TABLELANDS NSW

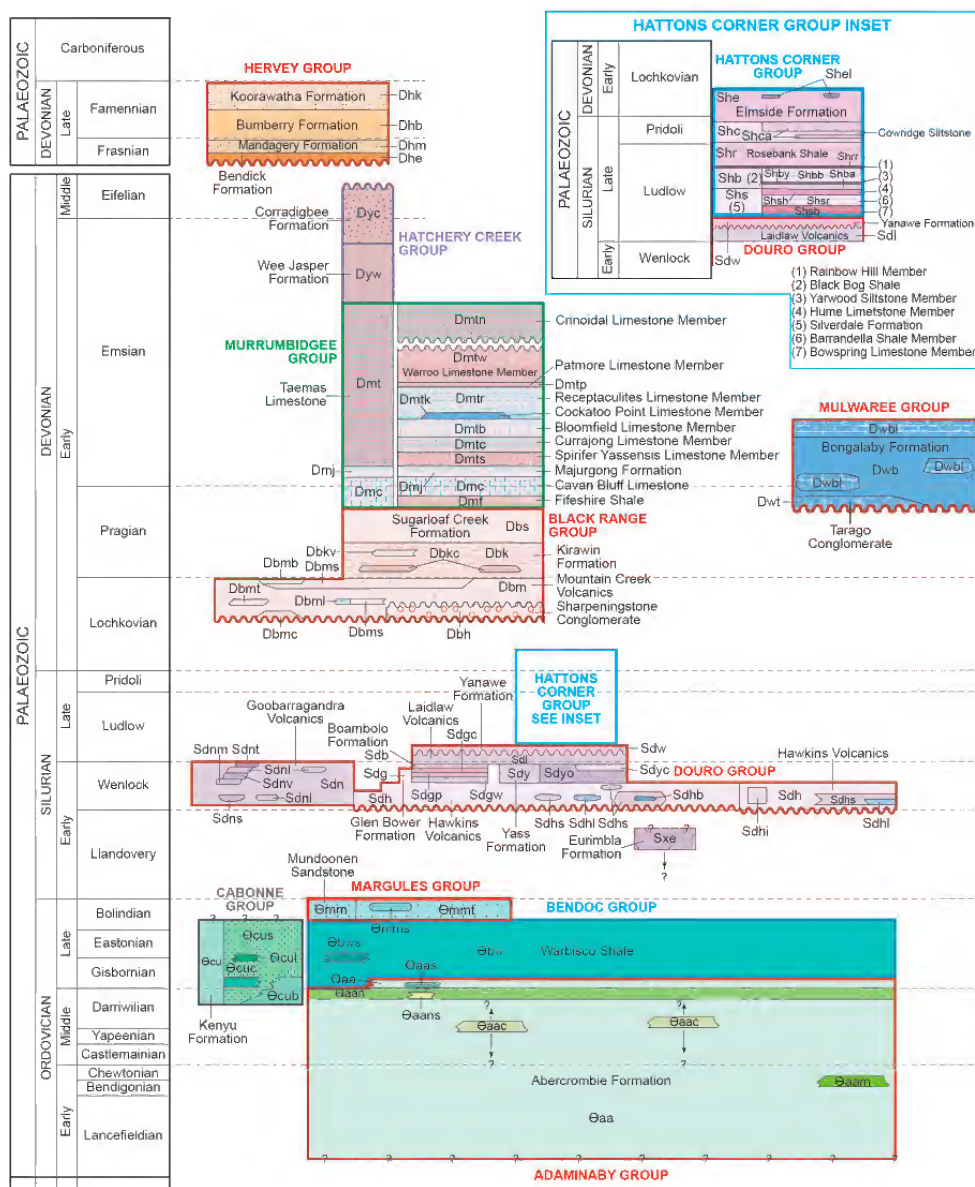
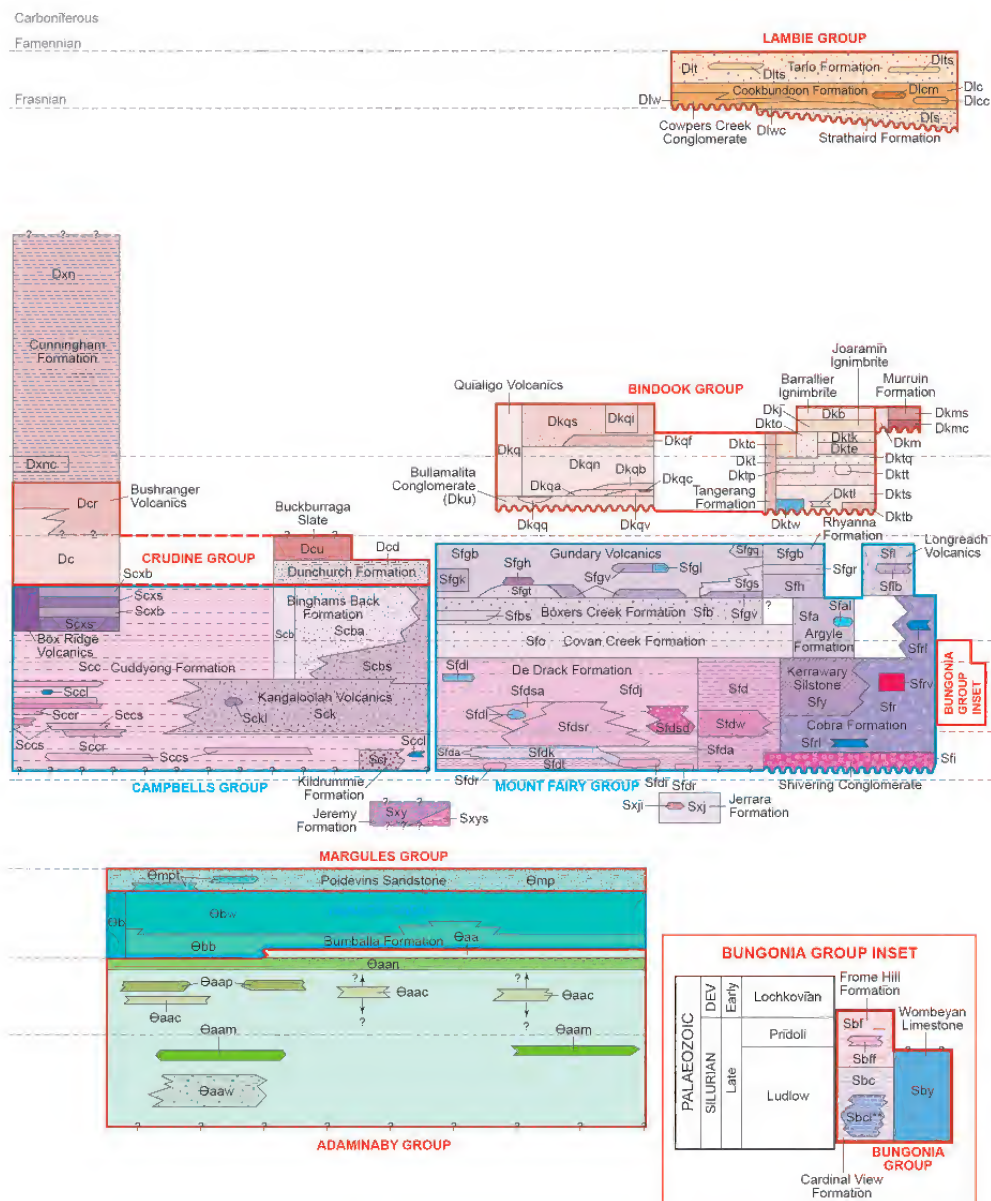


Figure 2 (above and right). Correlation chart for Ordovician, Silurian and Devonian fossiliferous strata (discussed in the text) in the Southern Tablelands region of southeastern New South Wales, mainly adapted from the Time-Space Plot in the Explanatory Notes for the Goulburn 1:250,000 Geological Sheet (Thomas and Pogson 2012), except for Mulwaree Group (modified from Fitzherbert et al. 2011). Units depicted on left side of figure are generally distributed in the western part of the region; those on the facing page are represented in the eastern part of the region. Stratigraphic groups are outlined in solid coloured lines (same colour as their names, in capital letters). Space constraints require many units at formation and member levels to be designated by three- and four-letter codes; for full description of these units refer to Thomas and Pogson (2012).



Peach Tree Chert Member (0aap on Fig. 2)

Murray and Stewart (2001) first identified conodonts including *Cordylodus* (now *Paroistodus*) *horridus* and *Histiodella* sp. from what is now called the Peach Tree Chert Member (their sample R16475) near the junction of Silent Creek and Oaky

Creek (approximately 20 km NW of Taralga), and recognised *Periodon aculeatus* in a separate chert band nearby (sample R16476). Resampling of the latter locality (GR 747433 6217083) during the GSNWS Goulburn mapping project yielded *Parostodus horridus*, *Periodon macrodentata* and *Histioidella*

sp. (Percival and Sherwin 2005). Those species were depicted by Percival and Zhen (2007:pl. 1, figs 5-9, 16) together with the less common *Baltoniodus* cf. *parvidentatus* and *Nordiora*? sp. Other conodonts recognised in the Peach Tree Chert Member include *Erraticodon* sp., *Multioistodus* sp., *Drepanoistodus*? sp., "*Oistodus*" *tablepointensis*, *Pseudobelodina*? sp., *Protopanderodus* sp. and *Spinodus spinatus*.

Paroistodus horridus locally ranges through most of Darriwilian 3 (although occurrences reported outside Australia rarely extend beyond the upper part of Da2). At least four species of *Histiodela* are known worldwide, and provide the basis for fine-scale subdivision of the Darriwilian from Da1 to the middle of Da3, but these species are extremely difficult to differentiate in chert sections. *Baltoniodus* cf. *parvidentatus* resembles a species typical of the early Darriwilian Kundian stage in Baltoscandia. *Pygodus anitae* (associated with *Paroistodus horridus* and *Histiodela* sp. in a chert from the Silent Creek fire trail on the Taralga 1:100,000 mapsheet) is of middle Darriwilian age (Da3, pre *Pygodus serra* Zone). Overall the age of the Peach Tree Chert Member is interpreted as middle Darriwilian (early-middle Da3).

Nattery Chert Member (0aan on Fig. 2)

Characteristic conodonts found in the Nattery Chert Member are *Periodon aculeatus* and *Pygodus serra* (Percival and Zhen 2007:pl. 1, figs 1-3, 10, 12), *Ansella* sp., *Baltoniodus* sp., together with a variety of generally indeterminate coniform elements. *Microzarkodina* sp. is rarely encountered. Where *P. aculeatus* and *P. serra* co-occur, the potential age of the sample corresponds to the range of *P. serra*, i.e. very late Da3 to the top of Da4. The presence of *P. aculeatus* alone may indicate a late Da3 age, as it slightly precedes the first occurrence of *P. serra*. However, the latter is relatively uncommon, and hence a sample containing just *P. aculeatus* may also be more broadly constrained to the entire range of that species, i.e. late Da3 to early Gisbornian (Gi1) – although this younger limit is somewhat imprecise. Stewart and Fergusson (1995) illustrated a specimen of *Pygodus serra* from the Sunlight Creek Formation (now regarded as Nattery Chert Member) in a cutting on the Bungonia-Goulburn road, where it is associated with *Periodon aculeatus*. Two occurrences of *Pygodus anserinus* were noted in the Nattery Chert Member on the Boorowa 1:100,000 mapsheet; this youngest species of *Pygodus* overlaps with the range of *P. serra* in latest Da4 time and extends into the early Gisbornian (Gi1). Thus all palaeontological evidence consistently points to a maximum age range

for the Nattery Chert Member of late Darriwilian (late Da3) to early Gisbornian (Gi1).

Other microfauna observed in thick sections of cherts from the Nattery Chert Member include radiolaria (generally poorly preserved as silica blebs, though occasionally with relic skeletal structure and spines), sponge spicules, and fragmentary acrotretide brachiopods (Percival 2012a).

Uppermost Abercrombie Formation (above Nattery Chert Member)

Graptolites are relatively common in two horizons within the uppermost Abercrombie Formation. Siliceous black siltstones interbedded with, and immediately overlying, the uppermost Nattery Chert Member contain pyritised graptolites, identified by L. Sherwin as *Dicellograptus geniculatus* and *Pseudoclimacograptus* cf. *riddellensis*. These indicate an age range of latest Darriwilian (Da4) to early Gisbornian (Gi1), consistent with the age of the chert. Also present in these siltstones is a trace fossil preserved in epirelief with three straight arms diverging at 120° from a central point (Percival and Sherwin 2004). This trace fossil could not be identified from the literature, and its significance is unknown. Elsewhere in shales in the upper Abercrombie Formation, *Nemagraptus gracilis* has been identified (Percival and Sherwin 2003). This graptolite is the zonal indicator for the early Gisbornian (Gi1) zone but also ranges through the entire Gisbornian stage. Constraints from fossils in underlying and overlying stratigraphic units imply that the most likely age for the top of the Abercrombie Formation is early Gisbornian.

Bendoc Group

Bumballa Formation (0bb on Fig. 2)

Most fossils obtained from the Bumballa Formation are graptolites, but at many localities these are poorly preserved, so identifications and age connotations are not necessarily precise. Typical species present include *Climacograptus bicornis*, *C.* cf. *cruciformis*, *Dicranograptus nicholsoni*, *D.* sp. and *Orthograptus calcaratus* subsp. The most diverse fauna occurs at GR 765682 6165816 and includes *Dicellograptus sextans*, *D.* cf. *divaricatus*, *D.* cf. *intortus*, *Nemagraptus gracilis*, *Reteograptus*? *geinitzianus*, *Pseudoclimacograptus* cf. *scharenbergi* and *Glyptograptus*? sp. (identifications by L. Sherwin). This assemblage, located approximately 320 m above a chert containing Darriwilian conodonts, clearly indicates a Gisbornian age, probably Gi1 (Percival and Sherwin 2004). A graptolite fauna from GR 764830 6216182 on the Taralga 1:100,000 mapsheet

includes several other species whose ranges overlap in the late Gisbornian (Gi2), including *Glossograptus ciliatus*, *Pseudoclimacograptus* sp., dicranograptid fragments and *Corynoides*? sp., associated with lingulate brachiopods and indeterminate caryocaridid arthropods (Percival and Sherwin 2005; Sherwin et al. 2006).

Conodonts found in cherts assigned to the Bumballa Formation at GR 747703 6216870 on the Taralga 1:100,000 mapsheet (Percival and Sherwin 2005) include a pygodiform element of *Pygodus anserinus* (with four clearly-defined rows of nodes), which dates this sample to the *anserinus* Zone (ranging from topmost Da4 to basal Gi1, i.e. straddling the Middle to Late Ordovician boundary). The haddingiform element of *Pygodus* is also present, as well as numerous elements of *Periodon aculeatus*.

Fergusson and Fanning (2002) illustrated trace fossils interpreted as unidentified animal tracks (i.e. grazing trails) on bedding planes at the base of turbidite beds in the Bumballa Formation from the Shoalhaven Gorge, and Jones et al. (1993) reported *Nereites* trace fossils from this area in rocks now attributed to the Bumballa Formation. Both occurrences imply that the ocean floor at the time of deposition of these turbidites was at least partially oxygenated, rather than being anoxic.

Warbisco Shale (0bw on Fig. 2)

Graptolites of Late Ordovician age were first documented from the Goulburn–Marulan–Bungonia region by Naylor (1936), who provided brief descriptions and line drawings of *Orthograptus quadrimucronatus* and *O. calcaratus tenuicornis*. Although not specifically referring to Naylor's paper, VandenBerg and Cooper (1992) examined other specimens attributed to *O. calcaratus tenuicornis* and concluded that its presence in Australasia was doubtful. Sherrard (1943) listed a large number of graptolite species (none of which were described or figured) from localities in the Jerrawa district, east of Yass. She distinguished two horizons, one probably in the latter part of the Gisbornian (from three localities), and the other level (recognised at 30 localities) of definite Eastonian aspect. From the Goulburn–Marulan–Bungonia area, Sherwin (1972) briefly noted the occurrence of conodonts preserved on bedding planes in siliceous shales (now assigned to the Warbisco Shale) with graptolite faunas of Gisbornian and Eastonian ages.

The majority of graptolites identified from the Warbisco Shale on the Goulburn 1:100,000 mapsheet (Percival and Sherwin 2004) and Taralga 1:100,000 mapsheet (Percival and Sherwin 2005)

are of Eastonian age. Similar fauna was collected from the Braidwood 1:100,000 mapsheet in the vicinity of Sally Trigonometric Station, about 7.5 km WSW of Tarago (Strusz and Nicoll 1973). The preservation of some specimens does not permit confident recognition of species necessary for precise age determinations, so the following faunal lists only include material that is distinctive or well preserved. The oldest species identified is *Climacograptus tridentatus*, indicative of a late Gisbornian (Gi2) age, from GR 767540 6181065. No species restricted to the earliest Eastonian (Ea1) zone were recognized. One assemblage from GR 765010 6169658 comprises long-ranging species that overlap in Ea2, such as *Dicranograptus nicholsoni*, *D. hians*, *Dicellograptus* sp., *Cryptograptus* cf. *insectiformis*, *Diplacanthograptus spiniferus*, *Orthograptus* cf. *amplexicaulis*, and *O. ex gr. pageanus*. Other graptolites of middle to late Eastonian (Ea2–4) age are widespread, including *Dicellograptus* species with the rhabdosome formed into a distinctive figure-8 shape (*D. cf. caduceus*), *D. flexuosus*, *D. elegans*, *D. n. sp. cf. D. minor*, *D. gravis*, *Orthograptus ruedemanni*?, *Dicranograptus kirki*, *Pseudoclimacograptus*? sp., *Leptograptus eastonensis*, *Ensignraptus caudatus* and *Normalograptus tubuliferus*. Williamson and Rickards (2006) described a similar fauna from weathered black shales now included in the Warbisco Formation at Ryrie Hill, 8 km SSE of Michelago (south of Canberra), to which they assigned an Eastonian 2–3 age, based on the presence of *Leptograptus flaccidus* cf. *macer*, *L. ?flaccidus spinifer*, *Dicellograptus morrissi*, *D. cf. caduceus*, *Climacograptus* [= *Ensignraptus*] *caudatus*, *C. [=Normalograptus] tubuliferus*, *C. mohawkensis*, *Orthograptus quadrimucronatus*, *O. calcaratus calcaratus*, *O. c. ?priscus*, *O. c. cf. vulgatus*, *O. c. aff. tenuicornis*, *O. amplexicaulis pauperatus*, *O. a. intermedius* and *Glyptograptus daviesi*. Graptolites found in the Warbisco Shale that are typical of (though not necessarily restricted to) the early Bolindian include *Appendispinograptus longispinus*, *Dicellograptus ornatus*, *D. cf. morrissi*, *Euclimacograptus hastatus*, *Leptograptus* sp. or *Pleurograptus* sp., *Orthograptus* cf. *thorsteinssoni* or *O. fastigatus*, *O. quadrimucronatus* and *O. cf. amplexicaulis*. The early Bolindian age of this association is confirmed by co-occurrence, e.g. at GR 765732 6151522 and GR 756841 6109803, of *Syracograptus uncinatus*, the zonal indicator species for Bo1 (although this is quite rare). This species was also noted at Ryrie Hill by Williamson and Rickards (2006), possibly from a different level to that yielding the middle Eastonian fauna. Very occasionally, e.g. at GR 758848 6128704, cherty silicified siltstone is present in the Warbisco

PALAEOZOIC PALAEONTOLOGY OF SOUTHERN TABLELANDS NSW

Shale. Thin sections prepared of this lithology reveal proximal fragments of graptolites, identified (by L. Sherwin) as *Diplacanthograptus spiniferus* of Eastonian 2-4 age. Conodonts are very rare, generally only represented by simple coniforms, including a possible eobelodiniiform element of *Belodina* sp.

Cabonne Group

Kenyu Formation (θcu on Fig. 2)

Percival et al. (2008) documented the conodonts *Belodina compressa*, *Scabbardella* cf. *S. altipes*, *Drepanoistodus suberectus*, *Panderodus gracilis*, *Periodon aculeatus*, *Phragmodus undatus*, *Protopanderodus liripipus*, *Yaoxianognathus wrighti*, and *Yaoxianognathus* sp. from an allochthonous limestone lens (θcul) towards the top of the Kenyu Formation. This fauna indicates a Late Ordovician (late Gisbornian to earliest Eastonian) age for the limestone. Also present in the insoluble residue were the acrotetide brachiopod *Scaphelasma?* sp., the discinide brachiopod *Orbiculoidea* sp., indeterminate large thick-shelled lingulide brachiopods, flat-spined gastropods and hyolithids.

EARLY SILURIAN STRATIGRAPHY AND BIOSTRATIGRAPHY

Eurimbla Formation (Sxe on Fig. 2)

Two samples attributed to this formation (defined by Thomas and Pogson 2012) give conflicting ages (Percival 2001). Thin sections of dark grey-black siltstone, from a small road quarry at GR 662240 6202708 on the Boorowa 1:100,000 mapsheet, contain fragments of graptolites that resemble hair-like species of *Monograptus* s.l. comparable with mid-late Llandoveryan forms (L. Sherwin, pers. comm.), together with very well-preserved spinose radiolaria, and a partially disaggregated sponge. This presumably represents the depositional age of the Eurimbla Formation. Another site nearby on the Gunnary Road yields clasts of translucent pale brown-yellow chert in which conodonts (predominantly *Paracordylodus gracilis*, with a few associated *Oepikodus evae*) are abundant and well-preserved. These chert clasts therefore have an age equivalent to the lower part of the *evae* Conodont Zone (Early Ordovician, late Bendigonian to early Chewtonian), and are interpreted as having been reworked into the lower Silurian Eurimbla Formation.

Jerrara Formation (Sxj on Fig. 2)

Naylor (1936) described several species of monograptids from what was then known as the

Jerrara Series near Bungonia, and subsequently (Naylor 1939) provided expanded faunal lists from this area. One locality on the Bungonia Road was resampled by Sherwin (1968) who reappraised the fauna, identifying *Streptograptus exiguus* and *Monograptus* cf. *M. nudus*, and assigning a late Llandoveryan (*turriculatus* Zone) age.

EARLY SILURIAN TO EARLY DEVONIAN

History of study of Yass Basin fossils

The Silurian to earliest Devonian rock succession in the Yass Basin contains arguably the best known and most intensively studied shallow water shelly faunas of this age in Eastern Australia. Fossil groups that are particularly well represented in the Yass Basin succession include trilobites, brachiopods, corals, conodonts and graptolites; other less conspicuous groups include stromatoporoids, molluscs (bivalves, gastropods, nautiloids), bryozoa, and algae. Relatively precise age constraints (particularly in the upper part of the succession) are provided by conodonts obtained from limestones that are interbedded with siltstones bearing abundant well-preserved graptolitic faunas.

The first documentation of fossils from the “Yass Plains” resulted from their discovery by the explorer Paul de Strzelecki, whose record of his journey in southeastern Australia included a description of a tabulate coral questionably referred to *Favosites gothlandicus* by Lonsdale (1845). Shortly thereafter, W.B. Clarke described the first trilobites from this area (Clarke 1848). Unfortunately, Lonsdale’s specimens (though still extant in the Sedgwick Museum at Cambridge University, UK) bear only very generalised locality details, and Clarke’s collection – the fossils from which had been described by de Koninck (1876-77, transl. 1898) – was destroyed in the Garden Palace fire in Sydney on September 22, 1882.

An important series of palaeontological investigations in the Yass Basin, particularly concerning trilobites and brachiopods, was undertaken between the 1870s and the early 1920s by Charles Jenkins, A.J. Shearsby, John Mitchell, Robert Etheridge Jr and Felix Ratte. The first three mentioned were self-taught amateur scientists; Robert Etheridge Jr was palaeontologist in the Geological Survey of NSW and subsequently Director of the Australian Museum. W.S. Dun, Etheridge’s assistant curator at the Geological Survey (and later palaeontologist there), also participated in several papers. Jenkins (1879) illustrated (without description) several trilobites. Ratte (1887a, 1887b) contributed two papers describing several species. Etheridge and

Mitchell (a local schoolteacher who later was head of Newcastle Technical College) had a productive collaboration describing the trilobite faunas of the Yass region, in a series of six major papers from 1892 to 1917 published in the *Proceedings of the Linnean Society of New South Wales*. Significant later trilobite studies revising and expanding these earlier works are those of Chatterton (1971), Chatterton and Campbell (1980), and Strusz (1980).

Pioneering work on the graptolites of the Yass Basin was carried out by T.S. Hall in 1903, but a detailed study of the faunas throughout the succession was not published for another 34 years. Kathleen Sherrard, initially with assistance from R.A. Keble, described a considerable number of Silurian graptolites, forming the basis for her subsequent recognition of several biostratigraphically significant assemblages (Sherrard and Keble 1937, Brown and Sherrard 1952). Many of the earlier identifications of Sherrard and co-workers have been systematically revised, initially by Jaeger (1967) and subsequently by Rickards and Wright (1999), establishing ties to the global standard graptolite zonation.

Study of the conodont faunas of the Yass Basin was part of a detailed Ph.D mapping project by A.G. Link in the late 1960s and early 1970s. Link (1971) reported initial results, followed by publication of the systematic descriptions of the faunas (Link and Druce 1972). Although based on the form-species concept prevalent at the time (prior to the establishment of multi-element taxonomy), this work was of great significance in establishing a rigorous biostratigraphic framework especially in the upper part of the succession. Subsequent analysis of the faunas (Simpson 1995) has revised the maximum age of the lower formations from Ludlovian to Wenlockian (see discussion later in this paper).

The history of research into Silurian brachiopods of the Yass Basin was recently reviewed by Strusz (2010b). The initial phase of systematic descriptions, commencing with Etheridge (1892b), Dun (1907), Mitchell and Dun (1920), Mitchell (1921, 1923) and Booker (1926), was followed in the 1940s by the studies of Johnston (1941), St Joseph (1942) and Brown (1949) who revised and synonymised several of Mitchell's (1923) species. Commencing in the 1980s, D.L. Strusz published descriptions of the Silurian brachiopods of the Canberra district, also recording identical species from the Yass Basin (Strusz 1984, 1985a). In a series of papers between 2002 and 2010, Strusz completed description and revision of all brachiopods represented in the Yass Basin.

Following the initial documentation of the diverse Silurian coral faunas by Lonsdale (1845) and de Koninck (1876), A.F. Foerste (1888) described a few rugosans (and trilobites) sent to his laboratory in the USA. Other early contributions on the rugosan faunas by R. Etheridge Jr (1881-1894, 1904c, 1913) and A.J. Shearsby (1905, 1906), and subsequently O.A. Jones (1932, 1936), were revised and expanded by Dorothy Hill (1940). Jones (1937) described favositid tabulates and collaborated with Hill to document the heliolitids (Jones and Hill 1940). Pickett and Jell (1974) and McLean (1974, 1976) have systematically revised some of the earlier identifications. Other generic reassignments have been made by Strusz and Munson (1997) for the rugosans, and Munson et al. (2000) for the tabulate corals and chaetetid sponges.

Reinterpretation of the age of the Yass Basin sequence based on conodonts

Link and Druce (1972) recognised four conodont assemblages in rocks of the Yass Basin, the oldest *Neoprioniodus excavatus* fauna succeeded by the *Spathognathodus* sp cf. *ranuliformis*, *Ancoradella ploeckensis*-*Kockelella variabilis*, and *Belodella triangularis*-*Polygnathoides siluricus* faunas. They suggested correlations with the conodont zonation of the Carnic Alps (Austria) established by Walliser (1964). Thus the two older Yass Basin faunas were inferred by Link and Druce (1972) to correlate with the Zone of *Ozarkodina crassa*, of early Ludlovian age, although this zonal indicator species was not recognised at Yass. The two younger assemblages contained the zonal indicator conodont species *A. ploeckensis* and *P. siluricus*, respectively, providing precise correlation with international biostratigraphic zonations. Graptolite faunas were consistent with a late Ludlovian to latest Pridolian age for the upper part of the succession, overlying the limestone containing *siluricus* Zone conodonts.

At the time of publication of Link and Druce's research, conodont taxonomy was just commencing a fundamental revolution which would see the elimination of single-element species nomenclature in favour of a multielement apparatus-based species concept. Link and Druce (1972) was also a pioneering work, in that there was no previous local Silurian biostratigraphic zonation using conodonts to correlate with. Link's mapping and stratigraphy was (with some minor revisions in nomenclature) sufficiently rigorous to be widely accepted to the present day. Not until the revision by Simpson (1995) of Australian Silurian biostratigraphy was a reassessment of the Link and Druce conodont faunas undertaken (Table 1).

PALAEOZOIC PALAEOONTOLOGY OF SOUTHERN TABLELANDS NSW

Yass Basin conodont identifications of Link and Druce (1972)	Revised and multielement identifications (based on Simpson and Talent 1995)
<i>Acodus curvatus</i>	<i>Walliserodus curvatus</i>
<i>Ancoradella ploeckensis</i>	<i>Ancoradella ploeckensis</i>
<i>Belodella devonica</i>	<i>Belodella silurica</i>
<i>Cordylodus? dubius</i>	<i>Coryssognathus dubius</i> [Sc element]
<i>Coryssognathus dentatus</i>	<i>Coryssognathus dubius</i> [Pa element]
<i>Distomodus curvatus</i>	<i>Coryssognathus dubius</i> [Pb, Pc]
<i>Hindeodella equidentata</i>	<i>Wurmiella excavata</i>
<i>Icriodus woschmidti</i>	possibly <i>I. woschmidti hesperius</i>
<i>Kockelella variabilis</i>	<i>Kockelella variabilis variabilis</i> & <i>K. variabilis ichnusae</i> S and C 1998
<i>Ligonodina elegans</i>	<i>Oulodus elegans</i>
<i>Ligonodina salopia</i>	<i>Kockelella variabilis</i> [Sc element]
<i>Ligonodina silurica</i>	<i>Kockelella variabilis</i>
<i>Lonchodina detorta</i>	
<i>Lonchodina greilingi</i>	<i>Kockelella variabilis</i> [Sb element]
<i>Lonchodina walliseri</i>	<i>Pseudolonchodina fluegeli?</i> or <i>Oulodus elegans</i>
<i>Neoproniodus bicurvatooides</i>	
<i>Neoproniodus bicurvatus</i>	<i>Ozarkodina confluens</i>
<i>Neoproniodus excavatus</i>	<i>Wurmiella excavata</i>
<i>Neoproniodus latidentatus</i>	
<i>Neoproniodus multiformis</i>	<i>Ancoradella ploeckensis</i> [M element]? or <i>Kockelella variabilis</i> [M element]
<i>Oneotodus? beckmanni</i>	<i>Pseudooneotodus beckmanni</i>
<i>Ozarkodina crassa</i>	
<i>Ozarkodina denckmanni</i>	
<i>Ozarkodina gaertneri</i>	<i>Ancoradella ploeckensis</i> [Pb element]?
<i>Ozarkodina media</i>	<i>Wurmiella excavata</i>
<i>Ozarkodina ortus</i>	
<i>Ozarkodina typica</i>	<i>Ozarkodina confluens</i>
<i>Ozarkodina zieglerei aequalis</i>	
<i>Ozarkodina</i> cf. <i>O. zieglerei tenuiramea</i>	
<i>Ozarkodina</i> cf. <i>O. zieglerei zieglerei</i>	<i>Kockelella variabilis</i> [Pb element]
<i>Ozarkodina</i> sp.	
<i>Panderodus gracilis</i>	<i>Panderodus unicostatus</i>
<i>Panderodus panderi</i>	<i>Panderodus recurvatus</i>
<i>Panderodus simplex</i>	<i>Panderodus unicostatus</i>
<i>Panderodus unicostatus serratus</i>	<i>Panderodus serratus</i>
<i>Panderodus unicostatus unicostatus</i>	<i>Panderodus unicostatus</i>
<i>Plectospathodus extensus</i> s.l.	<i>Wurmiella excavata</i>
<i>Plectospathodus extensus lacertosus</i>	
<i>Plectospathodus flexuosus</i>	<i>Ozarkodina confluens</i>
<i>Polygnathoides emarginatus</i>	
<i>Polygnathoides siluricus</i>	<i>Polygnathoides siluricus</i>
<i>Scolopodus duplicatus</i>	
<i>Spathognathodus fundamentatus</i>	<i>Kockelella absidata sardoa</i> S and C 1999
<i>Spathognathodus inclinatus inclinatus</i>	<i>Wurmiella excavata</i>
<i>Spathognathodus primus</i>	<i>Ozarkodina confluens</i>
<i>Spathognathodus</i> cf. <i>S. ranuliformis</i>	<i>Kockelella ranuliformis</i>
<i>Spathognathodus remscheidensis</i>	<i>Zieglerodina remscheidensis</i>
<i>S. cf. S. steinhornensis eosteinhornensis</i>	<i>Oz. remscheidensis eosteinhornensis</i>
<i>Synprioniodina silurica</i>	<i>Ancoradella ploeckensis</i> [M element]?
<i>Trichonodella excavata</i>	<i>Wurmiella excavata</i>
<i>Trichonodella inconstans</i>	<i>Kockelella variabilis</i> [Sa element]
<i>Trichonodella symmetrica</i>	<i>Ozarkodina confluens</i>
<i>Trichonodella trichonodelloides</i>	<i>Aspelundia? fluegeli</i>

Table 1 Revised identifications of those conodonts originally described from the Yass Basin using form-species nomenclature by Link and Druce (1972).

[Note: species not italicised in first column have no revised equivalent in second column] S and C 1998 = Serpagli and Corradini 1998 S and C 1999 = Serpagli and Corradini 1999

Wurmiella excavata (Branson and Mehl, 1933), previously known as *Ozarkodina excavata*, and recognised by Link and Druce (1972) as the form species *Neoprioniodus excavatus*, dominates the oldest assemblage. This is a prolific, easily recognised and long ranging multielement species distributed world-wide in the Silurian and Early Devonian. Although long presumed to occur no earlier than the late Wenlockian, it is now widely identified in strata of Telychian (late Llandoveryan) age. Link and Druce identified a few specimens of *W. excavata* in the Cliftonwood Limestone Member (of the Yass Formation) and the lower part of the Euralie Limestone Member (now assigned to the Yanawe Formation). Additional material of *W. excavata* was found in allochthonous limestones in the older Hawkins Volcanics (Fig. 3c-g) as a result of sampling undertaken during the Goulburn mapping program by the GSNSW (Thomas and Pogson 2012). However, due to its extended range, *W. excavata* is of no use as a zonal indicator, and other species must be sought to constrain the age of inception of deposition in the Yass Basin.

The characteristic form of the second of Link and Druce's conodont faunas, *Spathognathodus* sp. cf. *S. ranuliformis*, is compared with a species which is more restricted stratigraphically than *W. excavata*. Now referred to in multi-element nomenclature as *Kockelella ranuliformis* (Walliser, 1964), this species typically occurs in the eponymous *ranuliformis* Zone of lower to mid-Sheinwoodian age, but first appears in the underlying *Pterospathodus amorphognathoides* Zone (late Telychian to earliest Sheinwoodian) that spans the Llandovery–Wenlock boundary. Its local upper limit was placed by Bischoff (1987) within the *K. amsdeni* to *K. variabilis* zones (late Sheinwoodian to mid-Homerian, or about mid-Wenlockian). In a detailed evaluation of lineages in *Kockelella* species, Serpagli and Corradini (1999) came to a similar conclusion, noting the first appearance of *K. ranuliformis* in the mid-Telychian *Pterospathodus celloni* Zone, and placing its last appearance near the top of the *Ozarkodina sagitta rhenana* Zone, in the latest Sheinwoodian. Previously published Australian records of *K. ranuliformis* occurring in mid-Ludlow strata (base of *siluricus* Zone – cf. Link and Druce 1972, Simpson et al. 1993, Simpson and Talent 1995) are probably incorrect, and refer to aberrant specimens of the somewhat similar species *Ozarkodina crispera* (A. Simpson pers. comm. May 2006). There is some uncertainty in the identification (apparent from the cf.) of the Link and Druce species from Yass, but Simpson (1995) believed this corresponded to a late form of *K. ranuliformis*. Hence the age of the

Euralie Limestone Member of the Yanawe Formation (immediately below the Silverdale Formation) that contains this second conodont fauna is most likely no younger than mid-Wenlockian, not mid-Ludlovian as shown by Simpson (1995: text-fig. 2). We have now identified *K. ranuliformis* in allochthonous limestone blocks in the Hawkins Volcanics, towards the base of the Yass Basin succession (Fig. 3a-b).

This reassessment has significant age connotations for older units of the Yass Basin succession beneath the Yanawe Formation. The Hawkins Volcanics (in which *K. ranuliformis* is known to occur), Yass Formation and Laidlaw Volcanics most likely range in age from early to mid-Wenlockian (early Sheinwoodian to mid-Homerian). The Yanawe Formation and the lower half of the Silverdale Formation, up to the middle of the Bowspring Limestone Member, probably span the mid-Wenlockian to early Ludlovian (mid-Homerian to late Gorstian) interval. Units assigned to the *A. ploeckensis* Zone, of latest Gorstian to early Ludfordian age, include the upper Bowspring Limestone Member, the *Barrandella* Shale Member and lower Hume Limestone Member of the Silverdale Formation. The *P. siluricus* Zone extends through the upper Hume Limestone Member, lower Black Bog Shale and Yarwood Siltstone Member. Age dating of the overlying Yass Basin succession (upper Black Bog Shale, Rosebank Shale, and Cowridge Siltstone) is well-constrained by late Ludlovian and Pridolian graptolites. Our current knowledge of Yass Basin biostratigraphy, summarised in Strusz (2010b: fig. 1), demonstrates that this re-evaluation of the age, particularly of the oldest units, has doubled the estimated duration of sedimentation in the Yass Basin from about 5 Ma (at the time of Link and Druce's study) to approximately 10 Ma.

Douro Group

Goobarragandra Volcanics (Sdn on Fig. 2)

Isolated limestone pods (Sdnl) occurring within the Goobarragandra Volcanics in the Talmo–Galong district have been assigned a Silurian (most likely Wenlockian – Ludlovian) age on the basis of macrofauna, identified by Sherwin (1968) as including the corals *Aphyllum lonsdalei*, *Tryplasma* sp., *Heliolites daintreei*, halysitids (possibly *Acanthohalysites australis*), *Striatopora* sp. and pentamerid brachiopods (cf. *Kirkidium*). Attempts to increase the precision of this age determination during GSNSW mapping of the Yass 1:100,000 sheet were unsuccessful as conodont yields were extremely low, with only non-diagnostic coniform elements (*Panderodus gibber?*, and *Panderodus unicostatus* or *P. gracilis*) and one valve of the lingulide brachiopod *Paterula* sp. being recovered.



Figure 3. a-b, *Kockelella ranuliformis* (Walliser, 1964) from sample C2045, a, Pa element, MMMC5071, upper view (IY312-001); b, Pb element, MMMC5072, inner-lateral view (IY312-002). c-g, *Wurmiella excavata* (Branson and Mehl, 1933); c, Pb element, MMMC5073, from sample C2045, inner-lateral view (IY312-003); d-e, Pa elements from sample C2063, d, MMMC5074, outer-lateral view (IY312-004), e, MMMC5075, inner-lateral view (IY312-006); f, Sa element, MMMC5076, from sample C2063, upper-posterior view (IY312-005); g, Sc element, MMMC5077, from sample C2051, inner-lateral view (IY312-013). h-l, *Panderodus greenlandensis* Armstrong, 1990. h, Sd element, MMMC5078, from sample C2063, outer-lateral view (IY312-010); i, Sc element, MMMC5079, from sample C1859, outer-lateral view (IY312-015); j, Sa element, MMMC5080, from sample C2051, posterior view (IY312-016); k, P element, MMMC5081, from sample C2063, outer-lateral view (IY312-011); l, Sb element, MMMC5082, from sample C2051, outer-lateral view (IY312-017). m-n, *Panderodus* sp. A of Wang and Aldridge, 2010; m, falciform element, MMMC5083, from sample C2025, outer-lateral view (IY312-014); n, MMMC5084, from sample C2051, outer-lateral view (IY312-018). o, *Panderodus panderi* (Stauffer, 1940); falciform element, MMMC5085, from sample C2063, outer-lateral view (IY312-007). All from limestone blocks in the Hawkins Volcanics. Scale bar 100 μ m.

Hawkins Volcanics (Sdh, Sdhl, Sdhs on Fig. 2)

Sherwin and Strusz (2002) re-evaluated a graptolite specimen found in mudstones within the lower Hawkins Volcanics, determining it to be *Pristiograptus* ex. gr. *meneghini*. A comparable species *Pristiograptus* sp. cf. *P. meneghini*, described by Rickards et al. (1995) from the lower Panuara Formation in the Quarry Creek district, west of Orange, was assigned an age of “middle Wenlock, possibly in the range of *rigidus* to *linnarssoni* (= *flexilis*) zones” equating to the middle to upper Sheinwoodian. The age of the top of the Hawkins Volcanics is constrained by conodonts from the Euralie Limestone Member (of the overlying Yanawe Formation) that are most likely to be no younger than latest Sheinwoodian, or mid-Wenlockian (see preceding discussion on age of the Yass Basin sequence).

Biostratigraphically significant conodonts were recovered from several limestone blocks in the lower Hawkins Volcanics during GSNSW mapping of the Boorowa and Gunning 1:100,000 mapsheets. Most useful of these are *Kockelella ranuliformis* (Fig. 3a-b) which extends from the *Pterospirifer celloni* conodont Zone (late Llandoveryan) through its eponymous Zone to the succeeding *Ozarkodina sagitta rhenana* conodont Zone (early Wenlockian) in Europe and Greenland (Serpagli and Corradini 1999), and *Panderodus greenlandensis* Armstrong, 1990 (Fig. 3h-l) which in the Boree Creek area (near Orange) ranges from the uppermost *Pterospirifer amorphognathoides* Zone into the lower part of the succeeding *K. ranuliformis* Zone in the early Wenlockian (Cockle 1999). Although these two species do not co-occur in any of the samples examined, the overlap in their ranges in the early Wenlockian supports this as the maximum age of the lower Hawkins Volcanics. Long ranging conodonts identified in limestones within the Hawkins Volcanics on the Boorowa mapsheet (Percival 2001) include *Wurmiella excavata* (Fig. 3c-g) and other species of *Panderodus* (Fig. 3m-o).

Macrofossils from conodont sample C1858 on the Boorowa mapsheet (Percival 2001) include the tabulate coral *Cladopora seriatopora*, together with a new species of the stromatoporeid *Labechia* and large indeterminate strophomenide brachiopods. Occurring with *Panderodus greenlandensis* on the Gunning mapsheet (Percival and Sherwin 2003) are macrofossils including pentameride brachiopods (possibly *Kirkidium*) and a large solitary rugose coral.

The Hanaminno Limestone, a unit of very limited extent on the Boorowa 1:100,000 mapsheet (exposed in a creek east of Meringullalong locality at GR

668080 6193016, about 11 km NE of Boorowa and 13.5 km south of Frogmore), was formally defined in Thomas and Pogson (2012) on the basis of a single well-preserved Pa element attributed to the conodont *Astropentagnathus irregularis* Mostler, 1967, recovered from the residue of GSNSW conodont sample C1862 (Percival 2001). This identification supported a late Llandovery age for this limestone, distinguishing it from allochthonous limestone blocks (containing an early to middle Wenlock conodont fauna) assigned to the Hawkins Volcanics which are exposed in the nearby vicinity, although stratigraphic relationships in the area are obscured by alluvial deposits. However, both the original identification and the age inference were incorrect, and this conodont (Fig. 4a-b) is now regarded as a Pa element of *Kockelella*, most likely close to *K. variabilis* Walliser, 1957 (Peep Männik, pers. comm. 2016). In the sample it was associated with three elements of *Panderodus* sp. nov. (Fig. 6a). These conodonts are described in the Appendix to the present paper.

The age implied by the presence of *K. cf. K. variabilis* is certainly no older than Wenlock, possibly similar to that of the fauna in the Hawkins Volcanics, and removes the rationale of naming the Hanaminno Limestone as a separate, older, stratigraphic unit. We therefore recommend that further usage of this name be abandoned.

Sherrard (1952) described the gastropods *Euomphalopterus* cf. *E. alatus subundulatus* and *Temnospira monilis*, together with a new species of bivalve *Cosmogoniophora sinuosa*, from a locality known as “Vallance’s Hill”, about 2.5 km due east of the village of Murrumbateman, and from near Nanima Trig on strike approximately 3 km southeast, in sandstone within an area now mapped as Hawkins Volcanics. These shells (identifications of which are in need of revision) are associated with a brachiopod referred to *Howellella* cf. *elegans*, and a fragmentary echinoid (Philip 1963).

Bango Limestone Member (Sdhh on Fig. 2)

Common on weathered surfaces in the Bango Quarry is a halysitid coral that Brown (1941) identified as *Acanthohalysites pycnoblatooides*. However, Byrnes (in Pickett 1982) considered it closer to a species group now synonymised with *Falscicatenipora chillagoensis*. Pervasive recrystallisation of the limestone hinders a precise species determination. The tabulate coral fauna is assigned to the Dripstone Assemblage of Wenlockian to basal Ludlovian age (Munson et al. 2000). Conodont yields from the recrystallised limestone are extremely low, with only non-diagnostic coniform elements recovered.

Glen Bower Formation (Sdg, Sdgc on Fig. 2)

Rugose corals from the Glen Bower Formation, described by Hill (1940), include *Hercophyllum shearsbyi* – now *Phaulactis shearsbyi* – and *Entelophyllum latum*. Tabulate corals listed by Munson et al. (2000) as occurring in the Glen Bower Formation (based on an unpublished study by Byrnes 1972) include *Desmidopora multitalabata*, *D. sp.*, *Laceripora sp.*, *Favosites allani*, *F. gothlandicus*, *F. lichenaroides*, *F. regularis*, *F. yassensis*, *Cladopora seriatopora*, *Parastriatopora coreanica*, *Pseudoplasmopora heliolitoides*, *Propora conferta*, *Heliolites daintreei*, *Coenites juniperinus*, *C. pinaxoides*, *Alveolites spp.*, *Syringopora spp.*, and *Syringoporus cf. tonkinensis*. These forms are typical of the Hattons Corner Assemblage, as interpreted by Strusz and Munson (1997) and Munson et al. (2000), who correlated the Glen Bower Formation with the Cliftonwood Limestone Member of the Yass Basin.

In redescribing the brachiopod *Atrypoidaea* (*Atrypoidaea*) *australis*, Strusz (2007a) illustrated one specimen from the Glen Bower Formation at Glenbower, and listed several others in the Australian Museum collection that had been obtained in the Boambolo area, southeast of Yass.

Nautiloids *Actinoceras* and *Ormoceras* have been recognized in this formation by Teichert and Glenister (1952) but remain undescribed. From probable Glen Bower Formation at Forest Creek in the Boambolo district, Sherrard (1960) recorded the bivalves *Cyrtodonta lissa*, *Grammysia compressa*, *Paracyclas orbiculata*, *Grammysioidea declivis* and *Goniophora sp.*

Conodonts identified from the middle part of the Glen Bower Formation were reported by Feary (1986) as *Ozarkodina excavata* (now *Wurmiella excavata*), *Panderodus sp.* and a single element of *Pelekysgnathus dubius* (now *Corysognathus dubius*). These species occur in what Feary (1986) termed the upper Glen Bower Formation (equating to the Connell Member of the current terminology – Thomas and Pogson 2012) together with *Kockelella ranuliformis*. As discussed earlier, *K. ranuliformis* first appears locally in the *Pterospathodus amorphognathoides* Zone (late Telychian to earliest Sheinwoodian) and according to Bischoff (1987) it ranges into the *K. amsdeni* to *K. variabilis* zones (late Sheinwoodian, or early Wenlockian), although Serpagli and Corradini (1999) record its last appearance in European successions as near the top of the *Ozarkodina sagitta rhenana* Zone (latest Sheinwoodian). Hence the Connell Member is most likely no younger than early Wenlockian (latest Sheinwoodian) in age.

Yass Formation (Sdy on Fig. 2)

Most fossils described from the Yass Formation have come from the Cliftonwood Limestone Member (see below). The fauna listed here is from the undifferentiated Yass Formation.

Strusz (1984, 2005a, 2007a, 2009, 2010a) described the brachiopods *Atrypa* (*Atrypa*) cf. *A. dzwinogradensis*, *Atrypina* (*Atrypina*) cf. *A. latesinuata*, *Atrypoidaea* (*Atrypoidaea*) *australis*, *Agarhyncha australe*, *Hedeina bruntoni*, *Spirinella caecistriata* and *Tuvaerhynchus?* sp. from the Yass Formation. The ‘*Striispirifer*’–*Spirinella* Community to which this fauna was assigned by Strusz and Garratt (1999) should now be referred to as the *Hedeina*–*Spirinella* Community; according to their interpretation this fauna inhabited subtidal (to locally intertidal) depths generally consistent with Benthic Assemblage (BA) 3.

Bivalves described by Sherrard (1960) from the “Yass Series at Yass” include *Rhombopteria laminosa*, *Orthonota sp.*, *Ctenodonta* (*Tancrediopsis*) *victoriae*, *Grammysia compressa*, *Actinopterella minuta*, *A. formosa*, *Paracyclas orbiculata*, and *Goniophora sp.*

Cliftonwood Limestone Member (Sdyc on Fig. 2)

Brachiopods (*Spirinella caecistriata*) from this unit were first described by Johnston (1941). Strusz (1985b, 2002, 2003, 2007a, 2007b, 2010a) described the entire brachiopod fauna, including *Atrypina* (*Atrypina*) cf. *A. latesinuata*, *Spirigerina mitchelli*, *Coelospira cavata*, *Navispira?* *bicarinata*, *Epelidoaegiria minuta chilidifera*, *Morinorhynchus shearsbyi*, and *Salopina mediocostata*.

McLean (1976) listed rugose corals from the Cliftonwood Limestone Member as *Phaulactis shearsbyi*, *Holmophyllum multiseptatum*, *Rhizophyllum interpunctatum* and *R. robustum*. Tabulate corals recorded by Munson et al. (2000) include *Heliolites sp.*, *Alveolites piriformalis*, *A. sp.*, *Coenites pinaxoides*, *Syringopora sp.* and *Aulopora sp.*

Chapman (1909) described the ostracod *Leperditia shearsbii* from this unit.

Yanawe Formation (Sdw on Fig. 2)

Rugose corals recorded from the Euralie Limestone Member of the Yanawe Formation by McLean (1976) are *Phaulactis shearsbyi* and *Tryplasma lonsdalei* [now assigned to *Aphyllum*]. *Heliolites sp.* is the only tabulate coral recognised in this unit, according to Munson et al. (2000). Link and Druce (1972) noted the presence of the stromatoporoids *Anostylostroma*, *Intexodictyon*, *Clathrodiction*,

Hermatostroma and *Stromatopora typica*, none of which have been described or illustrated from this level.

Link and Druce (1972) also list several species of corals as occurring in the overlying Gums Road Limestone Member of the Yanawe Formation, although again only *Heliolites* sp. was recorded from this unit by Munson et al. (2000) in their survey of all tabulate coral species present in the Silurian of Australia.

Hattons Corner Group

Silverdale Formation (Shs on Fig. 2)

The *Ancoradella ploeckensis* conodont Zone spans the upper Bowspring Limestone Member, the Barrandella Shale Member and the lower Hume Limestone Member (Link and Druce 1972), indicating a latest Gorstian to early Ludfordian age for much of the Silverdale Formation (using the timescale of Strusz 2007c). The upper Hume Limestone Member contains conodonts of the ensuing *Polygnathoides siluricus* Zone, of mid to late Ludfordian age (late Ludlovian).

The dendroid graptoloid *Dictyonema delicatulum barnbyensis*, described from the Silverdale Formation by Rickards and Wright (1999), is otherwise known only from the Barnby Hills Shale near Neurea (SSW of Wellington in central west NSW), where it is associated with a late Ludlovian (*inexpectatus/kozlowskii* zones) graptolite assemblage (Rickards and Wright 1997).

Brachiopods from the Silverdale Formation described by Strusz (2002, 2003, 2007a, 2007b, 2010a) include *Atrypa* (*Atrypa*) cf. *A. dzwinogrodensis*, *Atrypoidea* (*Atrypoidea*) *australis*, *Dolerorthis exatriplade*, *Mesoleptostrophia* (*Mesoleptostrophia*) *quadrata* and *Morinorhynchus oepiki* [the latter two species restricted to the basal part of the formation], *Spirinella caecistriata*, *Nanattegia yassensis*, and possibly *Navispira? bicarinata*.

Bowspring Limestone Member (Shsb on Fig. 2)

Conodonts of the *Ancoradella ploeckensis* Zone make their initial appearance in the upper part of the Bowspring Limestone Member (Link and Druce 1972), indicating a latest Gorstian (early Ludlovian) age for this level.

The brachiopod fauna of the Bowspring Limestone Member is not as diverse as in other more shaly units of the Yass Basin succession, but one particularly distinctive form – the large pentameride *Aliconchidium yassi*, described by St Joseph (1942) and Boucot et al. (1969) – is restricted to this limestone member. Other brachiopods (described by

Strusz 2005b, 2007a, 2010a) include *Atrypa* (*Atrypa*) cf. *A. dzwinogrodensis*, *Spirinella caecistriata* and *Conchidium* cf. *C. hospes*. The presence of large pentamerides in the Bowspring Limestone Member (and their absence from the remainder of the Yass Basin succession) supports assignment of this fauna to the Pentamerinid Community that was characteristic of a rough water BA3 environment (Strusz and Garratt 1999).

Birkhead (1978) described stromatoporoids from the Bowspring Limestone Member including *Anostylostroma conjugatum*, *A. furcatum*, *Intexodictyon* cf. *I. perplexum*, *Parallelostroma maestermeyense*, and the new species *Plexodicyon hattonense*. An attungaiid sponge (unnamed new genus and species, known from only one specimen) was described by Pickett (1969) from this level at Silverdale.

Following the important contribution by Hill (1940) describing the rugose coral fauna, McLean (1974) redescribed *Yassia enormis*, and McLean (1976) listed all rugose corals known from the Bowspring Limestone Member, including *Phaulactis shearsbyi*, *Entelophyllum yassense*, *Zelolasma? praecox*, *Toquimaphyllum spongophylloides*, *T.? shearsbii*, *Yassia enormis*, *Stylopleura liliiformis*, *Pycnostylus dendroides*, *Aphyllum lonsdalei*, *Cystiphyllum* sp. cf. *bohemicum*, and *Holmophyllum colligatum*.

Favositid tabulate corals described (by Walkom 1912, and Jones 1937) from the Bowspring Limestone Member at Hattons Corner include *Favosites gothlandicus*, *F. triporus*, *F. richardsi*, *F. regularis*, *F. libratus* and possibly *F. allani*. The heliolitid fauna (Dun 1927; revised by Jones and Hill 1940) comprises *Heliolites daintreei*, *H. sp.*, *Pseudoplasmopora heliolitoides*, and *Propora conferta*. *Coenites* sp. is also present. These species lists include synonymies noted by Munson et al. (2000:54).

Barrandella Shale Member (Shsr on Fig. 2)

Strusz (2002, 2003, 2005b, 2007a, 2007b, 2009, 2010a) completely revised the brachiopod fauna of the Barrandella Shale Member and documented several new species; forms described include *Atrypa* (*Atrypa*) cf. *A. dzwinogrodensis*, *Atrypoidea* (*Atrypoidea*) *australis*, *Nucleospira paula*, *Ascanigypa glabra*, *Barrandina wilkinsoni*, *Clorinda minor*, *Dolerorthis exatriplade*, *ambocoeliinae?* gen. et sp. indet., *Endospirifer anxius*, *Nanattegia yassensis*, *Salopina mediocostata*, *Leptaena compitalis*, *Mesopholidostrophia bendeninensis*, *Epelidoaegiria minuta chilidifera*, *Morinorhynchus oepiki* and *Tuvaerhynchus? sp.*

Tabulate corals described or recorded from this unit (by Walkom 1912; Etheridge 1921; Jones 1927, 1937; Jones and Hill 1940), at Hattons Corner on the Yass River, include *Favosites gothlandicus*, *F. triporus*, *F. richardsi*, *F. regularis*, *F. libratus* and *F. allani*, *Hattonia etheridgei* (redescribed by Pickett and Jell 1974), *Heliolites daintreei*, *Alveolites piriformalis*, *Alveolites* sp., *Coenites* sp., *Syringopora* sp. and *Aulopora* sp.

The Barrandella Shale Member contains the greatest diversity of rugose corals in the Yass Basin succession, most of which were described by Etheridge (1890a, 1891, 1894, 1907) and Hill (1940). Species listed by McLean (1976) as occurring in this unit [with generic reassignments following Munson et al. (2000)], include *Entelophyllum yassense*, *Idiophyllum patulum*, *Zelasma? praecox* (redescribed by McLean 1976), *Phaulactis shearsbyi*, *Toquimaphyllum spongophylloides*, *T.? shearsbii*, *Stylopleura liliiformis*, *Mucophyllum crateroides*, *Pycnostylus congregationis*, *P. dendroides*, *Aphyllum lonsdalei*, *A. delicatulum*, *Tryplasma derrengullenense*, *Cystiphyllum* sp., *Rhizophyllum interpunctatum*, *R. yassense*, and *R. brachiatum* (described by McLean 1976).

Etheridge (1897) described the only known example of a polyplacophoran (chiton) in the Silurian of NSW, that he named *Chelodes calceoloides*, from this level. The type specimens of *C. calceoloides* were refigured by Hoare and Farrell (2004). The nautiloid *Ophioceras giblini* described by Chapman (1934) probably comes from the Barrandella Shale Member, according to Strusz (1996:104).

Bryozoa documented from this unit include the new species *Penniretepora lobata* and *Pesnostylus humei* of Crockford (1941), and *Fenestella yassensis* and *Heterotrypa humensis* described by Ross (1961).

The crinoids *Lecanocrinus breviararticulatus*, described by Chapman (1934), and *Pisocrinus yassensis*, described by Etheridge (1904b), also occur in this member. Unfortunately, the type material of both taxa was unable to be located for this review.

Strusz and Garratt (1999) selected the fauna of the Barrandella Shale Member to represent their *Barrandina–Atrypoides–Spirinella* Community that lived in a moderately deep water BA3-4 environment.

Hume Limestone Member (Shs on Fig. 2)

The fauna of the Hume Limestone Member is dominated by framework-building organisms such as corals, stromatoporoids and sponges, representative of the widespread *Favosites*–massive stromatoporoid Community that inhabited high energy environments

in tidal to high subtidal water depths of Benthic Assemblages 2-3, most likely BA3 (Strusz and Garratt 1999). Tabulate corals described from this unit include *Favosites regularis*, heliolitids (documented by Dun 1927 and revised by Jones and Hill 1940) including *Pseudoplasmodopora heliolitoides*, *Propora conferta*, *Heliolites daintreei* and *Heliolites* sp., and the alveolitines *Alveolites piriformalis*, *Alveolites* sp. and *Coenites* sp.; *Hattonia etheridgei* illustrated by Pickett and Jell (1974) probably came from this level. Hill (1940) documented the rugose coral fauna, though many of these species have subsequently been reassigned to other genera (see Strusz and Munson 1997). Rugose corals listed by McLean (1976) [generic attributions revised by Munson et al. 2000] include *Phaulactis shearsbyi*, *Entelophyllum yassense*, *Idiophyllum patulum*, *Zenophila walli*, *Toquimaphyllum spongophylloides*, *Mucophyllum crateroides*, and *Aphyllum lonsdalei*.

The stromatoporoid fauna described by Birkhead (1976) from the Hume Limestone Member includes *Plumatalinia balticivaga*, *P. densa*, *Rosenella dentata*, *Clathrodictyon delicatulum*, *C. tenuis*, *Actinodictyon keelei*, *Picnodictyon densum*, *Diplostroma yavorskyi*, *Schistodictyon conjugatum*, and *Parallelostroma maestermeyrense*. Pickett (1969) described the sponge *Astylosporgia radiata* from shales immediately above the Hume Limestone Member at Hattons Corner, although the exact stratigraphic horizon is uncertain.

Bryozoa from either this unit or the underlying Barrandella Shale Member include *Cheilotrypa* sp. A, described by Ross (1961), and an undescribed *Fistulipora*.

Brachiopods are rare in the Hume Limestone Member, relative to the remainder of the Yass Basin succession; only *Reticulatrypea pulchra*, redescribed by Strusz (2007a), possibly comes from this level – though that record is based on a locality description provided by Mitchell and Dun (1920) in the original description and has not been able to be corroborated. This species is certainly common in the overlying Black Bog Shale.

Tentaculites ornatus, described by Sherrard (1967) from limestone at Hattons Corner, comes from the Hume Limestone Member.

Black Bog Shale (Shb on Fig. 2)

Brachiopods are abundant and diverse within the Black Bog Shale. Many of the species listed here, described or revised by Strusz (2002, 2003, 2007a, 2007b, 2009, 2010a), are also present in the Yarwood Siltstone Member but some are confined to levels in the Black Bog Shale below that unit. The fauna includes *Atrypa* (*Atrypa*) cf.

A. dzwinogradensis [possibly present in the basal few metres of this unit], *Reticulatrypea pulchra*, *Atrypina* (*Atrypina*) cf. *A. latesinuata*, *Gracianella* (*Gracianella*) *kausi yassensis*, *Spirinella caecistriata*, *Spirigerina mitchelli*, *Atrypoidea* (*Atrypoidea*) *australis*, *Nucleospira paula*, *Coelospira cavata*, *Leptaena compitalis*, *Desistrophia papilio*, *Mesopholidostrophia bendeninensis*, *Endospirifer anxius*, *Epelidoaegiria minuta minuta*, *Hedeina bruntoni*, *Janius bowningensis*, *ambocoeliinae*? gen. et sp. indet., *Morinorhynchus oepiki*, *Nanattegia yassensis*, *Skenidioides thrinax*, *Isorthis* (*Arcualla*) *salicypontis* [lower part, below Yarwood Siltstone Member], *Miniprokopia* sp. [below Yarwood Siltstone Member], *Dicoelosia* cf. *D. johnsoni*, *Salopina mediocostata*, *Salopina pusilla*, *Talentella yassensis* and *Tuvaerhynchus*? sp.

Ross (1961) described the bryozoan *Calopora hattonensis* from this unit.

From the upper part of the Black Bog Shale, above the Yarwood Siltstone Member, Rickards and Wright (1999) described a diverse dendroid and monograptid graptolite fauna consisting of *Dictyonema elegans*, *Dendrograptus* sp., *Pristiograptus dubius*, *P. shearshyi*, *Linograptus posthumus posthumus*, *L. posthumus introversus*, *Bohemograptus bohemicus tenuis*, *B. praecornutus*, and *B. paracornutus*. Age of this fauna is, according to Rickards and Wright, equivalent to the late Ludlovian *praecornutus* biozone, and may potentially extend into the succeeding *cornutus* biozone in the top 2-3 m of the formation. Strusz (2010b) correlated these zones with the middle Ludfordian (middle to late Ludlovian).

Recently described from the Black Bog Shale is the new taxon *Porosothyone picketti*, the earliest-known holothurian body fossil (Jell 2010).

Probably also from this formation are bivalves described by Sherrard (1960), occurring on graptolite-bearing slabs; species recorded include *Actinopterella minuta*, *Pteronitella rugosa* and *Cardiola* (*Slava*) *fibrosa*.

Yarwood Siltstone Member (Shby on Fig. 2)

Some of the first fossils to be described from the Yass Basin came from the Yarwood Siltstone Member (initially termed the "Lower Trilobite Bed"), and included trilobites documented in a series of papers over two decades by Mitchell (1887, 1920) and Etheridge and Mitchell (1890, 1892, 1893, 1897, 1916, 1917). Revision of these faunas commenced fifty years later and continued for a further quarter-century (Chatterton 1971; Chatterton and Perry 1979; Chatterton and Campbell 1980; Strusz 1980; Thomas 1981; Adrain and Chatterton 1996). The

fauna as currently recognised was listed by D. Holloway (in Pickett et al. 2000) and includes the following: *Australoscutellum longispinifex*, *Batocara bowningi*, *B. etheridgei*?, *B. mitchelli*, *B. robustum*, *B. rothwellae*, *Ceratocephala bowningensis*, *C. phalaenocephala*, *C. vogdesi*, *Crotalocephalus? sculptus*, *C? silverdalensis*, *Decoroproteus australis*, *Dudleyaspis bowningensis*, *Diacanthaspis* (*Acanthalomina*) *parvissima*, *Japonoscutellum jenkinsi*, *Prantlia yassensis*, *Scharyia ritchei*, *Scotoharpes trinucleoides*, *Sphaerexochus lorum*, *Staurocephalus mitchelli*, and *Tropidocoryphe rattei* [reassigned to the new genus *Cirriticeps* by Holloway (2013)]. To this list can be added *Cyphaspis horani*, according to Adrain and Chatterton (1996).

The brachiopod fauna is equally diverse. A few species were originally described by Mitchell (1921), but the entire fauna has since been fully documented by Strusz (2002, 2003, 2005b, 2007a, 2009, 2010a) who formally named several species that remained unpublished from the Ph.D thesis of Kemezys (1967). The fauna comprises *Barrandina wilkinsoni*, *Reticulatrypea pulchra*, *Atrypina* (*Atrypina*) cf. *A. latesinuata*, *Gracianella* (*G.*) *kausi yassensis*, *Gracianella* (*Sublepada*)? sp., *Atrypoidea* (*A.*) *australis*, *Leptaena compitalis*, *Desistrophia papilio*, *Endospirifer anxius*, *Mesopholidostrophia bendeninensis*, *Epelidoaegiria minuta minuta*, *Janius bowningensis*, *Hedeina bruntoni*, *Nanattegia yassensis*, *Spirinella caecistriata*, *Strophochonetes kemezysi*, *Morinorhynchus oepiki*, *Skenidioides thrinax*, *Dolerorthis exatripalude*, *Dicoelosia* cf. *D. johnsoni*, *Salopina mediocostata*, *Salopina pusilla*, *Talentella yassensis* and *Tuvaerhynchus*? sp.

McLean (1976) recorded and redescribed only one rugose coral from the Yarwood Siltstone Member, *Entelophyllum yassense patulum*, now referred to *Idiophyllum patulum* according to Munson et al. (2000). However, Strusz and Garratt (1999) listed a more diverse coral fauna including *Zenophila walli*, *Phaulactis shearshyi*, *Tryplasma derrengullenense*?, *Mucophyllum* sp. and an unnamed sheet-like alveolite. Probably from this level (according to Hill 1941:table B) came the specimen of the tabulate coral "*Pleurodictyum*" *problematicum* recorded by Foerste (1888). Plusquellec (2015:24) suggested that this specimen shows affinities with cf. *Petridictyum* n. gen. *sensu* Plusquellec (2007).

Crockford (1941) described several new species of bryozoa from this level, including *Penniretepora lobata*, *Pesnastylus humei* and *Pseudohornera? retiformis* (though there is some doubt about the stratigraphic horizon from which the latter was collected).

Etheridge (1890b) described the machaeridian *Turrilepas mitchelli*, and several scolecodonts (annelid worm jaws) referred to *Arabellites bowningensis*, *Eunicites mitchelli*, and *Oenonites hebes*, from this level – all are in need of revision.

Only one graptolite is presently known from the Yarwood Siltstone Member (Rickards and Wright 1999), the dendroid *Dictyonema* sp. cf. *D. sherrardae* sherrardae.

The fauna of the Yarwood Siltstone Member was selected by Strusz and Garratt (1999) as representative of their *Aegiria*–Alveolitid Community, part of the deeper-water brachiopod-dominated *Dicoelosia*–*Skenidioides* Community Group. They interpreted this high-diversity assemblage as inhabiting subtidal to mid-shelf marine environments assigned to BA4 in moderately agitated water.

Rosebank Shale (Shr on Fig. 2)

Excluding the diverse faunas of the Rainbow Hill Member (listed below), graptolites are the only fossils described from the Rosebank Shale (Jaeger 1967; Packham 1968; Rickards and Wright 1999, 2004). The fauna includes *Dictyonema* sp. cf. *D. sherrardae* sherrardae, *Dictyonema* spp., *Pristiograptus dubius*, *P. shearsbyi*, *P. kolednikensis*, *Linograptus posthumus posthumus*, *Monograptus formosus*, *M. parultimus*, *M. pridoliensis*, *Crinograptus operculatus*, *Enigmagraptus yassensis*, *E. mitchelli* and ‘*Medusaegraptus*’ sp. The presence of *M. parultimus*, nominative species of the *parultimus* Zone, indicates a basal Pridoli age for this fauna and hence the Rosebank Shale spans the late Ludlovian, just extending into the Pridolian.

Rainbow Hill Member (Shrr on Fig. 2)

Previously known as the “Middle Trilobite Bed”, the trilobites of the Rainbow Hill Member have been described by Etheridge and Mitchell (1895, 1897), Mitchell (1919), Gill (1948), Chatterton (1971), Sherwin (1971), Strusz (1980), Sun (1990), and Ramsköld (1991). Currently recognized species were listed by Holloway (in Pickett et al. 2000:164) and include *Ananaspis latigenalis* [referred to *Paciphacops latigenalis* by Edgecombe and Ramsköld 1994], *Batocara robustum*, *Dalmanites meridianus*, *Decoroproteus yassensis*, *Dicranurus longispinus*?, *Kettneraspis rattei*, *Latiproteus bowningensis*, *Malimanaspis rhapsomyosa*, *Miraspis impedita*, *M. jackii*, and *Radnorina elongata*. Reassignment of *Odontochile meridianus* to *Dalmanites* implies that the trilobite-dominated *Odontochile* Community established by Strusz and Garratt (1999) to characterise the fauna of the Rainbow Hill Member

should be renamed the *Dalmanites* Community. This fauna inhabited quiet deeper water environments corresponding to BA4.

Strusz (2002, 2003, 2007a, 2007b) described the following species of brachiopods from the Rainbow Hill Member: *Leptaena compitalis*, *Mesoleptostrophia* (*Mesoleptostrophia*) *quadrata*, *Plectodonta* (*Plectodonta*) *psygmatia*, *Strophochonetes kemezysi*, *Salopina mediocostata*, *Salopina rainbowella*, *Talentella yassensis*, gen. et sp. indet. cf. *Becscia* sp., *Spirigerina mitchelli* and *Nucleospira paula*. A possible occurrence of *Clorinda minor* in this unit was noted by Strusz (2005b).

The bivalve *Goniophora* sp. was recorded by Sherrard (1960) as very rarely occurring in the Middle Trilobite Bed (=Rainbow Hill Member) at Bowning.

McLean (1976) redescribed the rugose coral *Palaeocyathus australis* from this unit, its only occurrence in the Yass succession.

The cystoid (echinoderm) *Austrocystites branagani*, first described by Brown (1964) from the Rainbow Hill Member, was redescribed and assigned to the genus *Eucystis* by Jell (2010). Another cystoid fragment from a similar stratigraphic level, identified as *Palaechinus* by Mitchell (1897), was reassigned to the new species *Trematocystis wrighti* by Jell (2010).

Cowridge Siltstone (Shc on Fig. 2)

Graptolites from the Cowridge Siltstone were first described by Sherrard and Keble (1937), and Brown and Sherrard (1952), although due to misidentifications they inferred a considerably older age than is now known to be the case. Jaeger (1967) discussed the earlier identifications and figured a specimen of *Monograptus bouceki* from this level. The fauna was revised and expanded by Rickards and Wright (1999) to include *Dictyonema* spp., *Pristiograptus shearsbyi*, *Monograptus parultimus*, *M. bouceki*, *M. transgrediens*, and *Monograptus* sp. *Monograptus parultimus* occurs in the lower part of the formation and *M. bouceki* first appears approximately 30 m higher, indicating that the Cowridge Siltstone spans both the *parultimus* and *bouceki* zones of the early to middle Pridoli.

Brachiopods described by Strusz (2002, 2003, 2007a, 2007b, 2010a) from the Cowridge Siltstone include *Strophochonetes kemezysi* and *Nanattegia yassensis* (both in basal beds of the formation), *Endospirifer anxius*, *Plectodonta* (*Plectodonta*) *bipartita*, *Meifodia*? cf. *M. lenticulata*, *Salopina pusilla*, *Talentella yassensis*, *Nucleospira paula* and *Navispira*? *bicarinata*.

A gastropod collected at Bowning, identified by Tassell (1980) as *Australonema*? sp. B, probably came from this formation.

Elmside Formation (See on Fig. 2)

The lower mudstone-dominated part of the Elmside Formation is of *transgrediens* Zone age (i.e. latest Pridoli Stage, or terminal Silurian), indicated by a graptolite fauna first described by Jenkins (1982a), and revised and expanded by Rickards and Wright (1999) who identified *Dictyonema elegans*, *Linograptus posthumus posthumus*, *Pristiograptus shearsbyi*, *Monograptus transgrediens*, *M. perneri elmsidensis*, *M. hornyi*, and *M. formosus jenkinsi*.

Brachiopods present in this latest Pridoli section (described by Brown 1949; Strusz 2000, 2003) include *Plectodonta* (*Plectodonta*) *bipartita* and *Strophochonetes kemezyi*.

Sherrard (1960) described numerous bivalves from this level, including *Nuculites pseudodeltooides*, *N. scissa*, *Ctenodonta* (*Tancrediopsis*) *victoriae*, *C. (T.) elegantula*, *C. (T.) minuta*, *Grammysia* (*Grammysioidea*) *declivis*, *G. ampla*, *Actinopterella lamellosa*, *A. minuta*, *Nuculopsis triangula*, *Rhombopteria laminosa*, *Lunulicardium* sp., *Modiolopsis elongata*, *Paracardium* cf. *P. filusum*, *Cypriocardinia contexta* and *Paracyclas orbiculata*.

Echinoderms are represented by a unique starfish described by Etheridge (1899) as *Sturtzaster mitchelli* – unfortunately this specimen was unable to be located in the Australian Museum collections, and is presumed lost. The new genus and species *Porosothyone picketti*, described by Jell (2010) from this unit, is the earliest-known holothurian body fossil (also present in the Black Bog Shale).

The nautiloid *Graftonoceras bowningensis*, originally described by Etheridge (1904a) as a species of *Cyclolituites* but reassigned by Teichert and Glenister (1952), possibly comes from the lower beds of the Elmside Formation (fide Strusz 1996).

Conodonts identified as early Lochkovian (*woschmidtii* Zone) in age were described by Link and Druce (1972) from limestone lenses in the Elmside Formation above the graptolitic mudstones in the lower part of the unit. Klapper and Johnson (1980) re-identified these conodonts as *Icriodus hesperius* (now *Caudicriodus hesperius*), an indicator of the basal conodont zone of the Early Devonian Lochkovian Stage.

Wright (1981) described the brachiopod *Notanoplia mitchelli* from the upper part of the Elmside Formation; an illustrated specimen doubtfully attributed to this species by Wright was reassigned by Talent et al. (2001:159) to *Notoparmella plentiensis* Garratt.

The trilobite *Leonaspis jenkinsi* was mentioned by Edgecombe (in Talent et al. 2000:205) as occurring in the Elmside Formation. Sherwin (1971)

redescribed the trilobites “*Phacops*” *serratus* and “*Phacops*” *crosslei* [= *Ananaspis crosslei*] from the “Upper Trilobite Bed” in the upper part of the Elmside Formation. Other trilobites from this level include longer-ranging taxa that first appear in the Yarwood Siltstone Member or Rainbow Hill Member, according to Strusz (1989, 1995), such as *Leonaspis rattei*, *Latiproetus bowningensis* and *Maurotarion bowningensis*.

Fletcher (1938, 1946) described the conularids *Conularia chapmani*, *C. mitchelli* and *C. bowningensis* from the “Upper Trilobite Bed”. These were revised by Sherwin (1969), who recognised *C. mitchelli* as a crushed nautiloid specimen; the other two species are valid.

From the ‘lower Gedinnian’ (i.e. earliest Devonian) part of the Elmside Formation, Birkhead (1978) described the stromatoporoids *Stachyodes* cf. *S. insignis* and *Stromatopora foveolata*, and Pickett and Jell (1974) described a new species of tabulate coral, *Hattonia fascitabulata*.

A primitive plant identified as *Dawsonites racemosa*, illustrated by White (1986), was found near Bowning. Trilobite pygidia of Early Devonian age associated with the specimen suggests that it comes from the Elmside Formation.

REGIONAL SILURIAN TO EARLIEST DEVONIAN STRATIGRAPHY OUTSIDE THE YASS BASIN

Campbells GroupKildrummie Formation (See on Fig. 2)

In their revision of a late Silurian conodont fauna originally described (in form species nomenclature) by De Deckker (1976) from the type section of the Kildrummie Formation, 11 km south of Rockley, Simpson and Talent (1995) and Simpson (1995) interpreted elements identified as “*Spathognathodus crispus*” and “*S. snajdrī*” by De Deckker to be Pa elements of *Kockella ranuliformis*, hence placing an age limit no younger than the basal *siluricus* Zone of the Yass Basin succession. Serpagli and Corradini (1999), who studied contemporaneous faunas from Sardinia, restricted the upper limit of *K. ranuliformis* to the mid-Wenlockian, near top of the Sheinwoodian (uppermost *Ozarkodina sagitta rhenana* Zone), although the species could conceivably range into the succeeding lower Homerian *sagitta* Zone. Simpson and Talent (1995) also recognised *Coryssognathus dubius* (comprising elements referred to the form species “*Dialdelognathus primus*”, “*Distomodus curvatus*” and *Acodus* cf. *curvatus* by De Deckker

1976), implying a Ludlovian age for the upper part of the Kildrummie Formation.

Mitchell (1923) described *Stropheodonta tarloensis* from outcrops now mapped as Kildrummie Formation in the Tarlo River southwest of Taralga; this brachiopod was tentatively reassigned to *Aegiria* (*Epelidoaegiria*) by Strusz (1982) but was subsequently considered by Strusz (2003:17) to be a *nomen dubium*, too poorly preserved to be confidently identified.

Cuddiyong Formation (Sec on Fig. 2)

Fossils are sparse in the Cuddiyong Formation, and consist of poorly preserved conodonts and occasional corals in limestones that are non-diagnostic of age. A graptolite found in the unit about 4.5 km west of Tuena, identified by L. Sherwin as *Bohemograptus* (possibly *B. bohemicus* subsp.), is indicative of a Ludlovian (late Silurian) age. Sherwin (cited in Percival 2012b) noted that while preservation is poor, the characteristic sickle shape of the rhabdosome is clear, as are a couple of thecae.

Mount Fairy Group

Shivering Conglomerate (Sfi on Fig. 2)

The only fossiliferous site known from this unit is located on the Oberon 1:100,000 mapsheet, immediately north of the boundary with the Taralga 1:100,000 mapsheet (Percival and Sherwin 2005). The lithology at this outcrop is heavily silicified, with poorly preserved macrofauna including a small rugose coral with long septa, resembling *Palaeophyllum*. Cross-sections of brachiopods observed in outcrop indicate the presence of pentamerides, implying most likely a Wenlockian or Ludlovian age.

Cobra Formation (Sfr on Fig. 2)

Valentine et al. (2006) documented a diverse fauna of linguliformean brachiopods and conodonts from the type section of the Cobra Formation in Murruin Creek near Taralga. Species described include the brachiopods *Kosagittella?* sp., *Rowellella?* sp., *Paterula* sp., *Orbiculoidea* sp., *Schizotreta* sp., *Artiotreta longisepta*, *Acrotretella dizeugosa*, *Opsiconidion ephemerus* and *O.* sp., together with several indeterminate taxa. The conodont fauna includes *Belodella anomalis*, *Dapsilodus obliquicostatus*, *Decoriconus fragilis*, *Panderodus recurvatus*, *P. serratus*, *P. unicostatus*, *Coryssognathus dubius*, *Oulodus* cf. *O. elegans*, *Wurmiella excavata excavata* and *Kockelella maenniki*. The last-named species is restricted to the early to middle *P. siluricus* Zone of the middle Ludlovian in Europe and North America (Serpagli and Corradini 1999), implying a

similar age for the sample near the top of the Cobra Formation in which it occurs. The formation may be as old as mid-Wenlockian at its base, according to Valentine et al. (2006), although a maximum late Wenlockian age – interpreted from coral faunas corresponding to the Hattons Corner Assemblage of Strusz and Munson (1997) and Munson et al. (2000) – is more plausible.

Another limestone sample from the Cobra Formation (Percival and Sherwin 2005) yielded numerous conodont elements, most of which are long-ranging species including *Panderodus unicostatus* and *Wurmiella excavata excavata*. The only biostratigraphically significant species, *Kockelella variabilis*, was represented by two fragmentary Sc elements and one broken but highly distinctive Pb element. This restricts the age of the sample to no younger than the basal *Polygnathoides siluricus* Biozone (middle Ludlovian), with a maximum age likely approximating the base of the Ludlow (late *K. crassa* Biozone) (Serpagli and Corradini 1999), although the species has been reported from Wenlock strata in China (Wang 2013).

Macrofossils in the Cobra Formation are present at two localities on the Taralga 1:100,000 mapsheet, where they occur as pavements of shelly fauna on bedding planes. Brachiopods are dominant, with *Mesopholidostrophia* cf. *M. bendeninensis* the most abundant, associated with *Atrypioidea* sp. and *Howellella* cf. *H. elegans*. The trilobite *Batocara* cf. *B. mitchelli* is present sporadically. Apart from hydrodynamic sorting, the bedding plane assemblages look to be largely undisturbed by waves, with all shells unbroken and some still articulated. Strusz (2003) noted that *M. bendeninensis* has a mid Ludlovian age, with the possibility that it might range to the end of the Ludlovian.

Evidence for the age of the Cobra Formation from both conodonts and macrofauna therefore is mostly consistent with a Ludlovian age, probably no younger than the top of the *siluricus* Zone, but potentially extending into the mid to late Wenlockian at its base.

De Drack Formation, Kingsdale Limestone Member (Sfdk on Fig. 2)

The Kingsdale Limestone Member contains a macrofauna characteristic of a quite shallow water depositional environment, evidenced by the presence of megalodont bivalves in the Kingsdale Limestone Quarry (near Goulburn). Although stromatoporoids are fairly common, other macrofauna is neither abundant nor diverse, with brachiopods (apart from occasional disarticulated pentamerides) poorly

represented. Conodonts are relatively uncommon to rare in the unit, with only one biostratigraphically useful species recovered. *Kockelella ranuliformis* (found in GSNSW conodont sample C1938, and questionably in C2058) is characteristic of a conodont biozone named for the species, but it also occurs in the underlying *Pterospiriferus amorphognathoides* Zone that spans the Llandovery–Wenlock boundary and ranges upwards into the early Wenlockian *K. amsdeni* to *K. variabilis* zones (Bischoff 1987).

The age of the Kingsdale Limestone Member therefore is most likely confined to the mid-Wenlockian, ranging from the upper *K. amsdeni* Zone into the overlying *K. variabilis* Zone. This is broadly in accord with limited data available from associated macrofossils. For example, a rugose coral from the Kingsdale Limestone Member, identified as *Cyathactis* cf. *C. variabilis*, is similar to *C. variabilis* from the Rosyth Limestone of the Boree Creek area, west of Orange (McLean 1975). The Rosyth Limestone is assigned to the *Pterospiriferus amorphognathoides* conodont Zone, which spans the Llandovery–Wenlock boundary. However, the range of the coral *Cyathactis* extends into the Ludlovian.

Sooley Volcanic Member (Sfds on Fig. 2)

GSNSW conodont sample C1962, from an allochthonous limestone block surrounded by Sooley Volcanic Member rocks in the upper De Drack Formation (above the Kingsdale Limestone Member), yielded a single specimen most likely referable to the distinctive conodont *Belodella anomalis*, which is known to range from the mid-Ludlovian *siluricus* Zone (basal Ludfordian) up to the top of the Pridolian.

Joppa Siltstone Member (Sfdj on Fig. 2)

The graptolite *Bohemograptus bohemicus* subsp. was found in an outcrop of the Joppa Siltstone Member behind the pumphouse at the Goulburn Waterworks Museum. This indicates a late Silurian (early to mid Ludlovian) age (Percival and Sherwin 2004).

Undifferentiated De Drack Formation (Sfd on Fig. 2)

A graptolite fauna including both the *bohemicus* and *tenuis* subspecies of *Bohemograptus bohemicus*, found in black shale of the undifferentiated De Drack Formation near Wowagin Creek, west of Taralga (Percival and Sherwin 2005), indicates a mid to late Ludlovian age (*scanicus* to *leintwardinensis* zones).

Several fossiliferous localities on the Braidwood 1:100,000 mapsheet are assigned to undifferentiated De Drack Formation (Percival and Sherwin 2008). On “Mulloon Creek”, a large coarsely ribbed pentameride

brachiopod has been identified as *Kirkidium* (*Pinguaella*) by D.L. Strusz. Another site yielded the graptolite *Bohemograptus bohemicus* subsp., found elsewhere in the Joppa Siltstone Member (see above) and in the Kerrawary Siltstone overlying the De Drack Formation. Conodonts recovered from a limestone within the De Drack Formation in this area include *Panderodus recurvatus*, *Wurmiella excavata*, *Pseudooneotodus beckmanni*, and a coniform element of *Coryssognathus dubius*.

Kerrawary Siltstone (Sfy on Fig. 2)

Although most specimens of graptolites from this formation are poorly preserved or are distorted by cleavage, sufficient of the diverse fauna has been identified to constrain the age of the unit quite precisely to the *nilssoni* and overlying *scanicus* zones of the early Ludlovian (Percival and Sherwin 2004; Percival 2012b). Species recognised in the region east of Goulburn (identifications by L. Sherwin; not all are co-occurring) include *Bohemograptus bohemicus* subsp., *Neodiversograptus nilssoni*, *Monograptus dubius*, *M. dalejensis*, *M. sp.*, *Cucullograptus progenitor cudalensis*, *Linograptus* cf. *L. orangensis* and *Saetograptus chimaera*. Associated macrofossils include a small strophomenide brachiopod, possibly *Aegiria* sp. or *Epelidoaegiria* sp. Of this fauna, only one species (*B. bohemicus*) has previously been described and illustrated (as *Monograptus bohemicus*) from the Taralga region, by Naylor (1936). Two of these taxa – *Cucullograptus progenitor cudalensis* and *Linograptus* cf. *L. orangensis* – were previously recognized in the Spring Creek and Quarry Creek region southwest of Orange (Rickards et al. 1995).

Limestone exposed in an abandoned quarry at Jerrara Creek, NW of Bungonia (GR 765575 6144050, Goulburn 1:100,000 mapsheet), was previously mapped as an allochthonous block occurring within the early Silurian Jerrara Formation, on the basis of a conodont fauna determined (by Percival 2012b) to be of late Llandovery to earliest Wenlock age. The limestone at Jerrara Creek yielded more than 200 conodont elements, many of which are deformed, with a CAI of 4.5 to 5. Reappraisal of this conodont fauna (Peep Männik, pers. comm. 2016) suggests that the age is considerably younger – most likely mid Ludlow (lower-middle *Polygnathoides siluricus* Biozone), based on the identification of *Kockelella maenniki* Serpagli and Corradini, 1998 (Fig. 4c-h). Associated conodonts (Figs 4i-s, 5, 6b-s, 7) include *Kockelella* sp. A, *Kockelella* sp. B, *Kockelella* sp. C, *Ozarkodina* sp., *Panderodus* sp. nov. and *Wurmiella excavata*. Also present are beyrichian ostracodes and an acrotretid brachiopod. *Kockelella maenniki*

has previously been recorded in the type section of the Cobra Formation in Murrumbidgee Creek near Taralga (Valentine et al. 2006). Though the Cobra Formation does not occur on the Goulburn 1:100,000 mapsheet, a slightly younger unit in the Mount Fairy Group, the Covan Creek Formation, is mapped between Goulburn and Bungonia wrapping around a very narrow tract of Jerrara Formation that includes large isolated limestone outcrops. All stratigraphic boundaries between these formations are depicted as inferred faults on the published map (they could also be interpreted as disconformable boundaries, though given the discontinuity of outcrop in the area it is difficult to be certain of their true nature). To explain the presence of a middle Ludlow limestone apparently occurring within the late Llandovery Jerrara Formation, one solution would be to reassign the siltstone beds in which the limestone blocks are emplaced to Kerrawary Siltstone, which has been mapped in this region, is of the right age, and underlies the unfossiliferous Covan Creek Formation. Alternatively, the boundaries between units might be better placed on the western side of the limestone blocks, thereby separating the early Silurian succession to the west from the late Silurian Mount Fairy Group to the east.

Boxers Creek Formation (Sfb on Fig. 2)

The brachiopod *Notanoplia* sp. and a trilobite referred to *Phacops* sp. have been identified from strata now attributed to the Boxers Creek Formation, near the top of that formation (Sherwin 1968, 1974). These fossils were obtained in the vicinity of the Bungonia Road–Koorringaroo Road junction, and in a nearby creek. They most likely indicate a Pridolian (latest Silurian) to Lochkovian (earliest Devonian) age.

Rhyanna Formation (Sfb on Fig. 2)

Various ages were obtained from allochthonous limestone blocks emplaced as an olistostrome near the base of the Rhyanna Formation (Percival and Sherwin 2005). The oldest, of late Wenlockian (latest Sheinwoodian to lower Homerian) age, was derived from a conodont fauna including *Panderodus unicostatus*, *P. panderi*, *Coelocerosodontus* sp., *Wurmiella excavata* s.l. and *Ozarkodina sagitta sagitta*, the latter (represented by a Pa and possible Sa elements) providing the definitive age constraint. Sections of another limestone revealed crinoid ossicles, heliolitid corals, *Thamnopora* (a thick-walled favositid coral), a tryplasmatic rugose coral, and a laminar stromatoporoid exhibiting well-developed astrorhizal canals (but not sufficiently

well preserved for identification). The *Thamnopora* is similar to a species common in the Nandillyan and Molong Limestones of the northern Molong High (J.W. Pickett, pers. comm.), suggesting a generalised Wenlockian to Ludlovian age. The residue of this sample (GSNSW conodont sample C2200) yielded conodonts with younger and inconsistent ages, implying that a variety of allochthonous limestone clasts were collected and processed together. Species identified included the long-ranging *Panderodus unicostatus*, *Belodella anomalis* which ranges from the *siluricus* Zone of the middle Ludlovian to the top of the Pridolian, and *Zieglerodina paucidentata*. This latter species is restricted to the basal Lochkovian *woschmidtii/hesperius* to *eurekaensis* zones, and does not overlap with the range of *Belodella anomalis* (although these species do occur in adjacent zones at the Silurian/Devonian boundary). Another sample yielded *Zieglerodina remscheidensis* which ranges from the basal Pridolian (*eosteinhornerensis* Zone) to the middle Lochkovian *delta* Zone. The most productive sample (GSNSW C2193) included *Caudicriodus hesperius* (zonal indicator for the early Lochkovian *woschmidtii-hesperius* Zone), *Wurmiella excavata*, *Oulodus* sp., *Panderodus unicostatus*, *P. recurvatus*, and *Belodella resima*. That assemblage indicates an earliest Devonian depositional age for the lower Rhyanna Formation.

Gundry Volcanics (Sfg on Fig. 2)

An allochthonous limestone (Sfg; GSNSW conodont sample C1939) in the Gundry Volcanics yielded more than 100 conodont elements including *Panderodus unicostatus*, *Belodella anomalis*, *Wurmiella excavata excavata*, *Kockella* sp. (Pa and Sb elements), together with the lingulate brachiopod *Opsiconidion* sp. (Percival and Sherwin 2004). Although this occurrence provides a maximum late Silurian age, ranging from the mid-Ludlovian *siluricus* Zone i.e. basal Ludfordian, to the top of the Pridolian, regional correlations suggest that the depositional age of the Gundry Volcanics is Early Devonian (Thomas and Pogson 2012).

Longreach Volcanics, Brayton Limestone Member (Sfb on Fig. 2)

Sampling of this unit (GSNSW conodont sample C1893), exposed in the Longreach limestone quarry on the Goulburn 1:100,000 mapsheet, yielded four conodont elements, including *Wurmiella excavata excavata* and *Amydrotaxis* sp., the latter indicating a Lochkovian to Pragian age (Percival and Sherwin 2004).

Bungonia Group**Cardinal View Formation, Lookdown Limestone Member** (Sbcl on Fig. 2)

Hundreds of conodont elements have been recovered from insoluble residues of the Lookdown Limestone Member (Percival and Sherwin 2004), but these are predominantly panderodids. Most useful biostratigraphically are platform (Pa) elements of *Ancoradella ploeckensis*, which is the index species for the *ploeckensis* Zone (early Ludlovian) and also ranges into the succeeding *siluricus* Zone of mid Ludlovian age. Also rarely present in residues of the member (GSNSW conodont sample C2030) are Pb and M? elements of a large *Ozarkodina*; these resemble *Ozarkodina* sp. nov. (illustrated in Percival 1998: fig. 4.3-4.4) from allochthonous limestone blocks in the Barnby Hills Shale. The suggested age for those *Ozarkodina* is early to mid Ludlovian, which accords with the age deduced for the Lookdown Limestone Member. Elements from GSNSW conodont sample C2012 that were attributed (by Percival and Sherwin 2004) to the Pa element of (*Kockelella ranuliformis* are closely comparable (if not identical) with specimens identified by Link and Druce (1972:pl. 9, figs 22-28) as the form-species '*Spathognathodus* sp. cf. *S. ranuliformis*' from the lower part of the Yass Basin succession.

Cook (1994) described a gastropod, *Michelia baueri*, and subsequently (Cook 1995) described a new genus and species of a megalodont bivalve *Schismadon bungoniensis* from the Lookdown Limestone Member, which has also yielded the rugose corals *Bungoniella clarkei* and *Hedstroemophyllum* sp. (Wright and Bauer 1995).

Shales overlying the Lookdown Limestone Member contain a graptolite fauna, reported by Carr et al. (1980) to include *Bohemograptus bohemicus tenuis*, indicating a mid-Ludlovian age.

Frome Hill Formation (Sbf on Fig. 2)

Copeland (1981) described a new genus of ostracode, *Bungonibeyrichia*, from "near the top of the upper shale unit, Bungonia Limestone" which suggests a level equivalent to the Efflux Siltstone Member of Bauer (1994), within the Frome Hill Formation above the Folley Point Limestone Member (Sbfff on Fig. 2). Camilleri et al. (2017) recently reassessed the species identification, describing *B. copelandi* and designating it as the type species of this taxon. The Frome Hill Formation also contains brachiopods, identified as *Eospirifer eastoni* and *Schizophoria* sp. by Jones et al. (1981), a trilobite referred by them to *Scabriscutellum* cf. *S. scabrum*, together with a conodont identified by Jones et al.

as "*Spathognathodus* cf. *S. remscheidensis*" which supported a Lochkovian age for the upper Bungonia Limestone. However, Mawson (1986) reassigned that conodont to *Ozarkodina steinhornensis eosteinhornensis*, indicative of a Pridolian age, and rejected the brachiopod identifications of Jones et al. (1981) due to inadequacy of the available material. Mawson also suggested that the trilobite belonged to the long-ranging subgenus *Scutellum* (*Scutellum*), but this identification has subsequently been rejected (Camilleri et al. 2017). Wright and Bauer (1995) mention the subsequent recovery of the characteristically Devonian brachiopod *Cyrtina* from the Sawtooth Ridge Limestone Member (not shown on Fig. 2) which forms the uppermost unit of the Frome Hill Formation.

EARLY TO MIDDLE DEVONIAN
STRATIGRAPHY OF THE BURRINJUCK AREA**Black Range Group****Sharpeningstone Conglomerate** (Dbh on Fig. 2)

Reworked clasts in the Sharpeningstone Conglomerate, derived from underlying Silurian strata (and hence providing evidence of the Bowning Orogeny) contain fragments of corals *Halysites* sp. (Wright and Byrnes 1980), *Aphyllum lonsdalei* and *Phaulactis shearshyi* (identified by Link and Druce 1972), and the rhynchonellide brachiopod *Tuvaerhynchus*? sp. described by Strusz (2009). The latter is otherwise only known from the Black Bog Shale and its Yarwood Siltstone Member in the Yass Basin. Link and Druce also identified 11 form species of conodonts from clasts in the conglomerate, spanning four of their assemblage zones and thereby implying that the erosion associated with the orogenic episode had sampled virtually the entire Yass Basin succession.

Kirawin Formation (Dbk on Fig. 2)

Maladybulakia angusi, a terrestrial myriapod arthropod, was described by Edgecombe (1998) from the Sugarloaf Creek Formation east of the Mountain Creek Road, about 5 km south of its junction with the Taemas–Wee Jasper road. However, some doubt exists regarding the precise stratigraphic level of this site (see discussion in Young 2011:87) as it corresponds to locality 10 of Campbell (1976), who attributed the strata to the underlying Kirawin Formation to which it probably belongs.

Sugarloaf Creek Formation (Dbs on Fig. 2)

The only fossil definitely known from this unit is

an undescribed fish plate assigned to the placoderm *Groenlandaspis*? (A. Richie, pers. comm. 1993) collected from material excavated during roadworks near the entrance to “Fifeshire” property on the lakeside road from Good Hope.

Murrumbidgee Group

Overview of palaeontological research

The Taemas–Wee Jasper area at the southern boundary of the Yass 1:100,000 mapsheet includes another series of significant palaeontological localities, such as the heritage-listed site known as ‘Shearsby’s Wallpaper’, world-famous fossil fish sites (Young 2011), and a rich and diverse invertebrate fauna that has been the subject of much research over the past century and a half. The Early Devonian biostratigraphy of this area was established by Philip and Jackson (1967), Philip and Pedder (1967) and Pedder et al. (1970), who documented a series of conodont zones and coral faunas in the Goodradigbee River valley exposures immediately north of Wee Jasper. Garratt and Wright (1988) integrated these zonations with their own Assemblage Zones based on brachiopods to provide an expanded macrofossil-based biostratigraphy with wide applicability to Lower Devonian rocks throughout NSW and Victoria.

Descriptions of conodont form species from the Wee Jasper area published in Pedder et al. (1970) have been superseded by modern conodont studies of Mawson et al. (1989) and Mawson and Talent (2000), culminating in a precise zonation for the Murrumbidgee Group (Basden 2003). The oldest conodont fauna (from the Cavan Bluff Limestone) is now confirmed as late Pragian (*pireneae* Zone) in age (Mawson et al. 1992), whereas that from the uppermost Taemas Limestone indicates a late Emsian age (*serotinus* Zone – Mawson 1987).

Fish faunas, both macrofossil and microvertebrate, have assumed increasing importance in Early Devonian biostratigraphy and regional correlation in recent years as the diversity of these fossils is explored, and their distribution is tied into the conodont zonation (Basden et al. 2000). Young (2011) summarised the history of research into fossil fish of the Murrumbidgee Group, with notable early contributions by Etheridge (1906) who described a lungfish skull (subsequently named *Dipnorhynchus*) found near old Taemas Bridge, Woodward (1941) who described the skull of the placoderm *Notopetalichthys hillsi*, and White (1952, 1978) who pioneered the technique of acid-etching limestone to obtain three-dimensional specimens of fish skulls from the Burrinjuck region. A major research program at ANU, Canberra, led by K.S.W. Campbell documented the

lungfish fauna (Campbell and Barwick, 1982–2007; Campbell et al. 2009), while the diverse placoderm fauna was described by G. Young and co-workers in publications spanning 1978–2009. A complete listing of papers describing Devonian fish from the Burrinjuck region to 2010 is given by Young (2011).

Rugose corals, initially studied by Etheridge (1892a, 1902, 1920) and Hill (1941) and subsequently comprehensively revised by Pedder (1964, 1965, 1967; in Pedder et al. 1970), are prominent in the Taemas and Wee Jasper areas. Currently-accepted rugose coral genera from the Cavan Bluff and Taemas limestones are listed by Zhen et al. (2000).

Other significant components of the invertebrate fauna of the Murrumbidgee Group have been described in several major monographic works (based on higher degree projects undertaken at ANU, Canberra under supervision of K.S.W. Campbell). Trilobites and associated brachiopods of the Taemas Limestone were described by Chatterton in 1971 and 1973 respectively. Ostracodes from the Taemas Limestone were documented by Reynolds (1978), and the gastropods have been described by Tassell (1982). Johnston (1993) provided the definitive systematic account of bivalves from the Cavan Bluff and Taemas limestones.

Cavan Bluff Limestone (Dmc on Fig. 2)

The Cavan Bluff Limestone [= Cavan Formation of previous authors] is well-dated on the basis of conodonts that were initially studied by Philip and Jackson (1967) and more extensively documented by these authors in Pedder et al. (1970). Subsequent revisions by Mawson et al. (1992) identified the Pragian–Emsian boundary, defined by the first appearance of the conodont *Polygnathus dehiscentis* (previously identified as *P. linguiformis dehiscentis* by those authors), as occurring within the Cavan Bluff Limestone approximately 72 m above the base of the section measured at Wee Jasper (just south of the boundary of the Yass 1:100,000 mapsheet). Species recovered by Mawson et al. included (in addition to non-platform elements) *Oulodus murrindalensis*, *Ozarkodina buechanensis*, *O. linearis*, *O. prolata*, *O. pseudomiae*, *O. selfi*, *Pandorinellina exigua philipi*, *Polygnathus dehiscentis abyssus* and *P. pireneae*. The latter is the index species for the latest Pragian *pireneae* Zone, which is represented in the lower Cavan Bluff Limestone.

Rugose corals were described from the Cavan Bluff Limestone initially by Etheridge (1902) and Hill (1941), with systematic revisions given by Pedder (1964, in Pedder et al. 1970). Genus reassignments by Zhen et al. (2000) and Pickett (2010) are reflected

in the following faunal list: *Pseudomicroplasma australasica*, *Embolophyllum aequiseptatum aequiseptatum*, *Tipheophyllum bartrumi*, *Sterictophyllum trochoides*, *Zelolasma gemmiforme*, *Z. abrogatum* and *Z. curtum*. Tabulate corals are abundant, notably *Favosites murrumbidgeensis*.

Bivalves were described by Johnston (1993) from calcareous sandstone and siltstone in the Cavan Bluff Limestone south of Mountain Creek (immediately south of the Yass 1:100,000 mapsheet boundary). He recorded the following fauna: *Nuculopsis* sp., *Polideveia* cf. *P. insolita*, *Mytilarca bloomfieldensis*?, *Glyptodesma buchanensis*, *Goniophora pravinassuta*?, *Guerangeria* sp., *Sanguinolites? concentricrugosa*, and *Schizodus oweni*.

The brachiopod *Spinella yassensis* first appears in the Cavan Bluff Limestone, although according to Strusz et al. (1970) it may be a different subspecies to that found in the lower Taemas Limestone. Chatterton (1973) also recognised *Athyris waratahensis* in the Cavan Bluff Limestone (confirmed by Talent et al. 2001).

Long (1986) and Lindley (2000) described acanthodian fish remains including jawbones with teeth, fin spines and scales, from exposures around Lake Burrinjuck between Taemas and Good Hope. Species described include *Taemasacanthus erroli*, *T. porca*, *Cavanacanthus warrooensis* and *Cambaracanthus goodhopensis*. According to Lindley (2002b:fig. 5) all specimens came from flaggy limestone associated with shale and quartzite in the basal part of the Cavan Bluff Limestone; *T. erroli* is also shown as ranging up into more massive algal limestones in the middle part of the formation, and also occurs in the lower units of the Taemas Limestone. Burrow (2002), however, argued that the incomplete nature of the specimens described by Lindley (2000) potentially allowed them all to be synonyms of *T. erroli*. An indeterminate ischnacanthid scale figured by Lindley is referred by Burrow to *Gomphonchus? bogongensis*. A new genus and species of arthrodire, *Bimbianga burrinjuckensis*, was described by Young (2005) from the Cavan Bluff Limestone just north of the Goodradigbee Valley, where it is associated with the arthrodire *Cavanosteus australis* described by Young (2004b). Campbell et al. (2009) noted fragmentary dipnoan material possibly referable to *Speonesydrion iani* from the lower part of the Cavan Bluff Limestone. Thelodont scales assigned to *Turinia* cf. *T. australiensis* were described and illustrated by Basden (1999) from the Cavan Bluff Limestone, and Basden (in Basden et al. 2000) and Basden (2003) illustrated a variety of fish scales and bone from this formation in a road section on the north side of the Taemas Bridge; these include material from

thelodont, placoderm (including *Goodradigbeon* sp.), acanthodian (including *Cheiracanthoides* sp.), chondrichthyan and dipnoan fish. The same exposure yielded an echinoid, *Cavanechinus warreni*, described by Brown (1967).

Majurgong Formation (Dmj on Fig. 2)

Fletcher (1964) described *Lingula murrumbidgeensis* from strata now referred to the Majurgong Formation at a locality given as “beyond woolshed on Bloomfield Station” in the Taemas district. Lingulide brachiopods are common elsewhere in maroon siltstones of this formation, such as in the Good Hope area. No internal details of this species have been described, and its generic attribution is in need of reassessment.

Microvertebrate remains illustrated from limestones in the Majurgong Formation in the vicinity of Taemas Bridge (Basden 2003) include *Ohiolepis* sp., *Onychodus* sp., and scales of *Ligulalepis toombsi*.

Taemas Limestone (Dmt on Fig. 2)

Rugose corals were described from the undifferentiated Taemas Limestone in the Wee Jasper area by Pedder (in Pedder et al. 1970), who established five informal ‘tetracoral teilzones’ (essentially range or interval zones) within this section. In stratigraphical order from oldest to youngest these are: *Chalcidophyllum recessum* zone, *Embolophyllum aggregatum aggregatum* zone, *Vepresiphyllum falciforme* zone, *Hexagonaria smithi smithi* zone, *Chalcidophyllum vesper* zone. These zones are difficult to apply precisely to the sections exposed around the eastern perimeter of the Burrinjuck Reservoir (Taemas–Good Hope), as this and the Wee Jasper areas only share similar coral species in the three lower zones. Due to the demonstrably diachronous nature of the contact with the underlying Majurgong Formation, the base of the Taemas Limestone is younger in the Wee Jasper area (where it probably lacks equivalents of the *Spirifer yassensis* Limestone Member, according to Pedder et al. 1970) than at Taemas. The Taemas Limestone at Wee Jasper may also extend slightly higher than in the Taemas succession. Remapping of the southern Goodradigbee Inlet NW of Wee Jasper (Lindley 2002b) allowed recognition there of four of the limestone members forming the lower Taemas Limestone in the Taemas–Good Hope area. The upper part of the Taemas Limestone in this western area (Warroo and Crinoidal Limestone Member equivalents) is represented by a reef facies.

From unspecified horizons in the Taemas Limestone, Ross (1961) described the bryozoans

Cyphotrypa murrumbidgeensis, *Stereotoechus shearsbyi*, *Leptotrypa* sp. A, *Homotrypa*? sp. B and *Ikclarchimedes warooensis* (from Por. 208, Parish of Warroo – possibly in the Receptaculites Limestone Member), and Bassler (1939) described the new species *Hederella browni*.

Spirifer yassensis Limestone Member (Dmts on Fig. 2)

The famous palaeontological heritage site known as ‘Shearsby’s Wallpaper’ (Cramsie et al. 1978: photos 9 and 10) was named for the avid amateur fossil collector and geologist A.J. Shearsby. It occupies a cutting on the old coach road leading down to the crossing of the Murrumbidgee River (now submerged by Lake Burrinjuck) downstream from Taemas Bridge. The cutting exposes numerous steeply-dipping bedding planes in the lower *Spirifer yassensis* Limestone Member that are covered in fossils of the brachiopod *Spinella yassensis*, previously referred to *Spirifer* prior to revision by Strusz, Chatterton and Flood (1970), together with the chonetid brachiopod *Johnsonetes cullenii* (Dun, 1904) redescribed by Strusz (2000). Other brachiopods recognised by Chatterton (1973) include *Athyris waratahensis*, *Howittia howitti* and “*Howittia*” *multiplicata*.

Also found at ‘Shearsby’s Wallpaper’ and its immediate vicinity were two almost complete skulls of the primitive lungfish *Dipnorhynchus sussmilchi*, including the holotype (Etheridge 1906; Hills 1933, 1941; Campbell 1965; Thomson and Campbell 1971; Campbell and Barwick 1982), an incomplete placoderm skull described by Young (1985) as *Shearsbyaspis oepiki*, and isolated trunk-shield plates of the petalichthyid *Lunaspis* sp. Fossil fish described from elsewhere in the *Spirifer yassensis* Limestone Member include the acanthodian (ischnacanthid) *Taemasacanthus erroli*, *Ligulalepis toombsi*, and species of *Ohioaspis*, *Ohiolepis*, and *Onychodus* described by Schultz (1968). Basden (2003) illustrated a scale of *Gomphonchus*? *bogongensis* and a fragment of a platelet of *Lunaspis* sp. from this level. Placoderms described by Young (1981, 2004b, 2005) from the *Spirifer yassensis* Limestone Member in the Goodradigbee Valley, north of Wee Jasper, include *Arenipiscis westolli*, *Cavanosteus australis* and *Bimbianga burrinjuckensis*; *Cavanosteus australis* also occurs at this level at ‘Shearsby’s Wallpaper’. The arthrodire *Parabuchanosteus murrumbidgeensis*, described by White and Toombs (1972) from the *Spirifer yassensis* Limestone Member and younger units of the Taemas Limestone, was synonymised with *Buchanosteus confertituberculatus* by Young (1979). From a similar horizon at Wee Jasper, Long

et al. (2014) described the buchanoosteoid placoderm *Richardosteus barwickorum*.

Sherrard (1967) described the tentaculitids *Tentaculites chapmani* and *Nowakia* aff. *N. acuarua* from this locality. Probably this was also the site from which the ostracod *Primitia yassensis*, described by Chapman (1914) was collected by A.J. Shearsby; Chapman noted the locality in Portion 65, Parish of Taemas, as the “Cavan cutting” and mentioned associated specimens of the brachiopod *Chonetes cullenii*, now *Johnsonetes cullenii*.

Undescribed nautiloids recognised in this unit by Browne (1959) include *Pectinoceras*, *Buchanoceras*, *Macrodomoceras* and *Polyelasmoceras*?, comparable at species level with those described by Teichert and Glenister (1952) from other Lower Devonian limestones in eastern Australia.

Conodonts from the *Spirifer yassensis* Limestone Member belong to the *dehiscens* Zone of the earliest Emsian, which commences in the upper Cavan Bluff Limestone. Species recognised (Basden 2003) include *Polygnathus nothoperbonus*, *Oulodus murrindalensis*, *Ozarkodina buchanensis*, *Oz. linearis*, *Oz. prolata*, and *Pandorinellina exigua exigua*.

Currajong Limestone Member (Dmtc on Fig. 2)

Species of conodonts identical to those in the underlying *Spirifer yassensis* Limestone Member continue into the Currajong Limestone Member, implying that the latter is of *dehiscens* Zone age (earliest Emsian) for almost all its stratigraphic thickness. However, the uppermost beds may be of the succeeding *perbonus* Zone age (Basden 2003).

Coral fauna D of Philip and Pedder (1967), equivalent to the *Chalcidophyllum recessum* teilzone of Pedder (in Pedder et al. 1970), ranges through the Currajong Limestone Member, with specimens of this rugosan particularly abundant in bands in the lower part. *Embolophyllum asper* is associated with *C. recessum* only in the lowermost beds of this unit in the Wee Jasper area. The tabulate coral *Syringopora speleanus*, described by Etheridge (1902), is also present in the lower part of the member.

Burrow (2002) described acanthodian fish scales from the Currajong Limestone Member, including *Nostolepis* sp. cf. *N. taimyrica*, *Cheiracanthoides* sp. cf. *C. comptus*, *Gomphonchus*? *fromensis*, and *Gomphonchus*? *bischoffi*. Jawbones of two new species of acanthodian (ischnacanthid) fish *Taemasacanthus narrengullenensis* and *T. cooradigbeensis*, associated with *T. cf. erroli* Long, were described by Lindley (2002a) from two levels within the Currajong Limestone Member near Good Hope and in the Goodradigbee Valley. A new genus and species of

dipnoan (lungfish), *Cathlorhynchus trismodipterus*, was described by Campbell et al. (2009) from the basal Currajong Limestone Member in the Wee Jasper area. In the Taemas area, another dipnoan named *Dipnorhynchus kurikae* occurs in the upper half of this unit (Campbell and Barwick 1985).

Bloomfield Limestone Member (Dmtb on Fig. 2)

Conodont faunas from the Bloomfield Limestone Member are predominantly of *perbonus* Zone (early Emsian) age, although there is some possibility that the lowermost beds of the unit are of *dehiscens* Zone (earliest Emsian) age (Basden 2003).

No corals have been described from this level in the Taemas–Good Hope region of the eastern part of Burrinjuck Reservoir, but *Embolophyllum aggregatum* occurs in the Bloomfield Limestone Member in the Goodradigbee Valley north of Wee Jasper (Pedder et al. 1970). The tabulate coral *Desmidopora nicholsoni*, described by Etheridge (1902) from Cave Flat (now Cave Island) at the former confluence of the Goodradigbee and Murrumbidgee rivers, probably also comes from this unit.

Fish are represented in this unit in the Taemas – Good Hope area and in the Goodradigbee Valley by the dipnoans *Dipnorhynchus sussmilchi*, *D. kurikae* and *Speonesydrion iani* (Campbell et al. 2000, 2009) and the acanthodian (ischnacanthid) *Taemasacanthus narrengullenensis* (described by Lindley 2002a). From a level correlated with the upper Bloomfield Limestone Member at Goodradigbee Inlet, Young (2004a, 2009) described the new arthrodire taxa *Cathlesichthys weejasperensis*, *Dhanguura johnstoni*, *Elvaspis tuberculata* and *E. whitei*. *Brindabellaspis tensioi* Young, 1980, an acanthothoracic placoderm, is likely from this level or the slightly younger Receptaculites Limestone Member.

Johnston (1993) described numerous bivalves from the uppermost Bloomfield Limestone Member (his localities R1a and R4), transitional in the case of R1 into the overlying Receptaculites Limestone Member. This interval may correspond in other areas of the Taemas Limestone succession to the newly recognised Cockatoo Point Limestone Member. Bivalves found in the Bloomfield Limestone Member include: *Nuculites* sp., *Nuculopsis* sp., *Mytilarca bloomfieldensis*, *Cornellites cattellus*, *C. campbelli*, *Limoptera murrumbidgeensis*, *Tolmaia erugisulca*, *Actinopteria* cf. *A. murrindalensis*, *Pseudaviculopecten etheridgei*, *Phorinoplax striata*, *Nargunella comptorae*, *Goniophora pravinasuta*, *G. duplisulca*, *Cypricardinia sinuosa*, *Sanguinolites?* *phlyctaenatus*, and *Eoschizodus taemasensis*. All these species apart from *P. etheridgei* were newly recognised by Johnston (1993).

Cockatoo Point Limestone Member (Dmtk on Fig. 2)

As this stratigraphic name has only recently been introduced in the Taemas – Good Hope area (Thomas and Pogson 2012), there has not been a long history of its use in published palaeontological descriptions. The dipnoans [lungfish] *Dipnorhynchus kurikae*, described by Campbell and Barwick (1985) from the vicinity of Cave Island in Burrinjuck Reservoir (collected when the water level was low), and *Speonesydrion iani* (see Campbell and Barwick 1983, 1984, 2007) obtained from limestone in the Goodradigbee Valley near Wee Jasper, potentially come from an equivalent level in the western area of outcrop of the Taemas Limestone, where they occur in the transition between the Bloomfield and Receptaculites limestone members of this area.

Receptaculites Limestone Member (Dmtr on Fig. 2)

Large specimens of the postulated dasycladacean alga *Receptaculites australis* are (or were – many having been removed by collectors) characteristic of this unit and give the member its name. They were first described from “Humewood” property by Etheridge and Dun (1898). However, not all of the type material they illustrated belongs to *R. australis*; as pointed out by Byrnes (1968), one example of another Early Devonian receptaculitid, *Ischadites struszi* that is preserved in matrix typical of the Garra Formation from the Wellington Caves district, was mistakenly included with the Burrinjuck specimens.

The sponge *Devonospongia clarkei*, redescribed by Howell (1957) and Pickett (1969), occurs in this limestone; it is one of the few fossils from the Murrumbidgee Valley that is recognisable from the monographic study by de Koninck (1876–1877) based on collections made by W.B. Clarke that were destroyed in the Garden Palace fire of 1882.

According to Chatterton (1973), the rugose coral *Xystriphyllum mitchelli* is found in biostromal bands or lenses about 60 m above the base of the Receptaculites Limestone Member rather than occurring at the base as claimed by Browne (1959). Hill (1941) described “*Cystiphyllum*” cf. *americanum* from the Receptaculites Limestone Member near Taemas Bridge; that coral was referred to an indeterminate species of *Plasmophyllum* by Pedder (in Pedder et al. 1970). Occurrence of this coral in the Taemas succession provides an important tie-point to the section in the Goodradigbee Valley described by Pedder et al., where it is found associated with *X. mitchelli* in the *Vepresiphyllum falciforme* zone.

Although Browne (1959) noted that the Spirifer *yassensis* Limestone Member was probably the source

of the tabulate coral described by Etheridge (1920) as *Columnopora* (*Gephuropora*) *duni*, Etheridge's own description suggested that this coral came from "near the Sponge Limestone, from which it may have been derived" which implies that the original level was the Receptaculites Limestone Member. This coral is now regarded as a species of *Favosites* with unusual morphological features interpreted as commensal worm tubes; Pickett (2010) noted that this association was described by Sokolov (1948) as *Phragmosalpinx australiensis*.

Trilobites described by Chatterton (1971) from his locality A on the boundary between the Receptaculites Limestone Member and Warroo Limestone Member have been subsequently revised, with current determinations including *Cyphaspis dabrowni* redescribed by Adrain and Chatterton (1996), *Ceratocephalina vexilla* revised by Ramsköld (1991), *Kettneraspis clavata* reassigned by Ramsköld and Chatterton (1992), and *Maurotarion struszi* revised by Adrain and Chatterton (1995). Edgell (1955) described *Acanthopyge* (*Mephiarges*) *bifida*, subsequently referred by Temple (1972) to *Acanthopyge* (*Jasperia*), from probably an equivalent level in the Goodradigbee Valley sequence.

Brachiopods in this unit tend to be concentrated at certain levels where silicification was optimal. The lower part of the member on "Bloomfield" property at the eastern side of Lake Burrinjuck near Taemas Bridge is the type locality for *Malurostrophia flabellicauda* Campbell and Talent, 1967. The majority of the brachiopod fauna was described by Chatterton (1973) mostly as new species, although some identifications have since been revised or reassigned by Talent et al. (2001:160). From the lower part of the Receptaculites Limestone Member, Chatterton described *Craniops australis*, *Salopina kemezyi*, *Cymostrophia dickinsi* [= *Mesodouvillina* (*Protocymostrophia*) *dickinsi*], *C. multicostella*, *Malurostrophia flabellicauda*, *M. flabellicauda reverta* [= *Malurostrophia flabellicauda s.s.*], *Leptostrophia clarkei*, *Schuchertella murphyi*, *Parachonetes flemingi* and *P. konincki* [both species redescribed by Strusz 2000], *Protochonetes culleni* [now *Johnsonetes culleni*, redescribed by Strusz 2000], *Ambothyrus runnegari*, *Coelospira dayi*, *Atrypa penelopeae*, *Anatrypa erectirostris*, *Athyris waratahensis*, *Cyrtina* aff. *C. wellingtonensis*, *Howittia howitti*, *H. multiplicata*, *Spinella yassensis*, *Quadrithyrina allani*, *Howellella* aff. *H. textilis*, *Hysterolites* sp., *Callipleura?* sp., *Eoglossinotoechia linki*, *Adrena expansa*, *Cydimia robertsi*, *C. parva*, and *Micidus shandkyddi*.

With the exception of *Mesodouvillina* (*Protocymostrophia*) *dickinsi*, *Hysterolites* sp.,

Callipleura? sp., *Cydimia robertsi* and *C. parva*, all of the above brachiopod species are also represented in Chatterton's Assemblage A from the top of the Receptaculites Limestone Member, with the addition of the following species: *Aulacella stormeri* [= *Dalejina philipi*, according to Talent et al. (2001:160)], *Malurostrophia flabellicauda* [synonymised by Talent et al. with Chatterton's *M. flabellicauda reverta*, *M. minima* and *M. aura*], *Spinulicosta campbelli*, *Cyrtinopsis* aff. *C. cooperi* [= *Plicocyrtina crenulata* Gratsianova and Talent], *Delthyris hudsoni*, *Browneella browneae*, *Pugnax oepiki*, *Adrena cernua* [synonymised with *A. expansa* by Talent et al.], and *Micidus?* *glaber*. *Johnsonetes latus* from this level was revised by Strusz (2000).

Reynolds (1978) documented a diverse fauna of ostracodes (22 genera and 33 species, 21 of which were new) from the Receptaculites Limestone Member. These included *Renibeyrichia pulcher*, *R. pustulosa*, *Thuringobolbina australis*, *Acinacibolbina anteropinnata*, *Subligaculum?* sp. A., *Nezamyslia carinata*, *Gyrgathella garryi*, *Cavanites robustihamatus*, *C. minilobatus*, *Hanaites* sp. A., *Hyperchilarina devonica*, *Libumella foliis*, *Berounella verrucosa*, *B. thymosa*, *B. trifolispina*, *B. spinosa*, *B. sp.*, *Tricornina robusticerata*, *Coniferina humensis*, *Bairdiocypris reynoldsi*, *B. astalis*, *Praepilatina* sp. A., *Tubulibairdia tumida*, *Newsomites dorsemmus*, *Acanthoscapha brevicristata*, *A. aff. A. laterispina*, *Cavellina* sp., *Batalaria epicopella*, *Risboa sarculina* and *Ampuloides* sp. A., together with several indeterminate forms.

Tassell (1980, 1982) described gastropods from this unit, the majority of which were recognized as new species. The fauna includes *Ptychosphaera convolutus*, *Coelocyclus hadroni*, *Tropidodiscus centrifugalis*, *Retispira retifera*, *Straparollus* (*Euomphalus*) *leptoni*, *Straparollus* (*Serpulospira?*) sp., *Arizonella?* *conoidea*, *Mourlonia subglobosa*, *Oehlertia pioni*, *Bembexia micula*, *Bembexia* sp., *Hesperiella* sp., *Umbotropis mesoni*, *Coelozone?* sp., *Trochonema* sp., *Trochonema?* *nodosa*, *Holozone?* *protoni*, *Platyceras* (*Platyceras*) sp. A., *Platyceras* (*Platyceras*) sp. B., *Naticopsis* (*Naticopsis*) *taemasensis*, *Murchisonia* (*Murchisonia*) *turris*, *Murchisonia* (*Murchisonia*) *fermioni*, *Murchisonia* (*Ostioma*) *bloomfieldia*, *Mesocoelia quarki*, *Michelia darwini*, *Stegocoelia* (*Stegocoelia*) *bononi*, *Taemasotrochus giganticus*, *Mitchellia striatula*, *Loxonema altacostatum*, *Palaeozygopleura muoni*, *Hemizyga* (*Hyphantozyga*) *granifera*, *Subulites* (*Fusispira*) sp., *Leptotygyma australe*, and *Ianthinopsis ornatus*.

Johnston (1993) described a very diverse bivalve fauna (dominated by new species) from the lower

part of this unit, including *Polidevcia* cf. *P. insolita*, *Deceptrix*? *clarkei*, *Nuculites* sp., *Nuculopsis* sp., *Solemyidae* sp. indet., *Mytilarca bloomfieldensis*, *Rhomboteriidae* gen et sp. nov., *Cornellites cattellus*, *C. campbelli*, *C. talenti*, *Limoptera murrumbidgeensis*, *Tolmaia erugisulca*, *Actinopteria* cf. *A. murrindalensis*, *Pseudaviculopecten etheridgei*, *Phorinoplax striata*, *Nargunella comptorae*, *Goniophoraprinasuta*, *G. duplisulca*, *Cypricardinia sinuosa*, *Sanguinolites*? *phlyctaenatus*, *Cimitaria*? sp., *Grammysioidea* sp., *Eoschizodus taemasensis*, *Schizodus truemani*, *Paracyclas proavia*, *P. rugosa*, *P. alleni*, and *Crassatellopsis lenticularis*. From the top of the Receptaculites Limestone Member, Johnston recorded the bivalves *Deceptrix*? *clarkei*, *Nuculites* sp., *Solemyidae* sp. indet., *Mytilarca bloomfieldensis*, *Rhomboteriidae* gen et sp. nov., *Cornellites cattellus*, *Goniophora duplisulca*, *Cypricardinia sinuosa*, *C. minima*, *Eoschizodus taemasensis*, *Schizodus truemani*, *Paracyclas rugosa*, and *Crassatellopsis lenticularis*.

Campbell and Barwick (1985, 2000) described the dipnoan *Dipnorhynchus kurikae* from the Receptaculites Limestone Member in the Goodradigbee Valley. The placoderm *Murrindalaspis wallacei* was described from this level both at Taemas and in the Goodradigbee area by Long and Young (1988). Giffin (1980) documented the following vertebrate microfauna from the lower 65 m of the Receptaculites Limestone Member: *Skamolepis fragilis*, *Ohioaspis tumulosa*, *Ohiolepis* sp., *Cheiracanthoides comptus*, an indeterminate acanthodian spine, *Onychodus*? *sigmoides*, *Onychodus*? sp. teeth, *Ligulalepis toombsi*, and paleoniscoid scales. Further acanthodian fish scales including *Nostolepis* sp. cf. *N. taimyrica* and *Gomphonchus*? *fromensis* were described by Burrow (2002). Basden (2003) illustrated *Cheiracanthoides* sp. cf. *C. wangi* and ischnacanthid scales from this level at Taemas, and a scale of *Murrindalaspis* from the Receptaculites Limestone Member at Wee Jasper. New taxa of brachythoracid placoderms described from this area by Young (1981) include *Arenipiscis westolli* and *Errolosteus goodradigbeensis*.

Bryozoa are represented in the Receptaculites Limestone Member by *Semicoscinium vallatum* and possibly also by *Ikelarchimedes warooensis*, described by Crockford (1941) and Ross (1961), respectively.

Tentaculites chapmani, described by Sherrard (1967) from Portion 208, Parish of Warroo, downstream from Taemas Bridge on the north bank of the Murrumbidgee River opposite 'Shearsby's Wallpaper', may also come from this level.

The age of the Receptaculites Limestone Member, based on conodonts, is early Emsian (*perbonus* Zone) (Basden 2003).

Warroo Limestone Member (Dmtw on Fig. 2)

The Warroo Limestone Member also yields conodonts of *perbonus* Zone age (early Emsian), possibly extending into the overlying *inversus* Zone in the uppermost beds (Lindley 2002b, Basden 2003).

Brachiopods described by Chatterton (1973) from this unit in the Taemas area include *Craniops australis*, *Isorthis spedeni*, *Resserella careyi*, *Muriferella hillae* [= *M. punctata*, according to Talent et al. 2001], *Aulacella philipi* and *A. stormeri* [both assigned to *Dalejina philipi* by Talent et al.], *Cymostrophia dickinsi*, *Taemostrophia patmorei*, *Malurostrophia minima* and *M. bella* [both assigned to *Malurostrophia flabellicauda* by Talent et al.], *Leptostrophia clarkei*, *Schuchertella murphyi*, *Parachonetes konincki*, *Spinulicosta campbelli*, *Ambothyris runnegari*, *Coelospira dayi*, *Cyrtina* aff. *C. wellingtonensis*, *Howittia howitti*, *Hysterolites* sp., *Delthyris hudsoni*, *Eoglossinotoechia linki*, *Pugnax oepiki*, *Adrena cernua* [synonymised with *A. expansa* by Talent et al.] and *Micidus shandkyddi*. Campbell and Chatterton (1979) further documented *Coelospira dayi*, and Strusz (2000) revised *Johnsonetes latus* (from the lower part of the unit) and *Septachonetes melanus*.

The only trilobite described from this level (Chatterton et al. 1979) is *Acanthopyge* (*Lobopyge*) sp.

Johnston (1993) described bivalves, mostly new species, from the lower to middle part of the Warroo Limestone Member, including *Polidevcia* cf. *P. insolita*, *Deceptrix*? *clarkei*, *Nuculites* sp., *Mytilarca bloomfieldensis*, *Rhomboteriidae* gen et sp. nov., *Cornellites cattellus*, *Goniophora duplisulca*, *Cypricardinia sinuosa*, *C. minima*, *Eoschizodus taemasensis*, *Paracyclas rugosa*, *Crassatellopsis lenticularis*, and *C. yongei*.

Fish remains from the Warroo Limestone Member were compared by Findlay (1996) to *Arenipiscis westolli*. Lindley (2002b) documented the acanthodian *Taemasacanthus narrengullenensis* and fragmentary ischnacanthid material including jawbones and scales, together with *Cheiracanthoides comptus* and a new species of *Onychodus*, *O. yassensis*.

Crinoidal Limestone Member (Dmtn on Fig. 2)

Basden (2003) assigned an *inversus* and *serotinus* Zone age (middle to late Emsian) to the Crinoidal Limestone Member. However, evidence for conodonts

characteristic of the *inversus* Zone age is minimal and that zone may be absent, due to a disconformity between the Warroo Limestone Member and the Crinoidal Limestone Member (Chatterton 1973).

Findlay (1996) described fish fossils from this unit in the Taemas area, including cf. *Errolosteus goodradigbeensis*, cf. *Arenipiscis westolli*, and cf. *Parabuchanosteus murrumbidgeensis*. Other fish have been described from laterally equivalent strata near the top of the Taemas Limestone exposed in the Goodradigbee Valley, north of Wee Jasper. These include a new species of petalichthyid placoderm described by Young (1978) as *Wijdeaspis warrooensis*, and a new species of the dipnoan (lungfish) *Dipnorhynchus*, *D. cathlesae*, described by Campbell and Barwick (1999). The latter was collected approximately 197 m below the base of the Hatchery Creek Group, at a level probably equivalent to the Crinoidal Limestone Member, though lacking the distinctive crinoidal fauna associated with that unit. Immediately beneath the Hatchery Creek Group, Campbell and Barwick identified a white, thin-bedded limestone 69 m thick and commonly cross-bedded, which they interpreted as having been deposited in the intertidal zone. Only ptyctodont fish teeth, together with rare fragmentary macrofossils, are present in this limestone, which they imply is transitional between the underlying marine limestones and the overlying fresh water clastic-dominated sediments forming the Hatchery Creek Group.

Hatchery Creek Group

Corradigbee Formation (Dyc on Fig. 2).

Outcrop of the Hatchery Creek Group is largely confined to the Brindabella 1:100,000 mapsheet, where it is bounded by the Goodradigbee Valley to the east, the Burrinjuck Granite to the west, and Burrinjuck Reservoir to the north. Two formations have been recognised in this area by Hunt and Young (2010) – the Wee Jasper Formation (Dyw on Fig. 2, including conglomeratic and sandstone facies) in the lower part, overlain by the finer-grained Corradigbee Formation.

Young and Gorter (1981) described a fish fossil fauna from calcareous nodular mudstone at least 1500 m above the base of the clastic-dominated non-marine sequence that conformably overlies limestones of the Murrumbidgee Group (Taemas Limestone). This locality is now regarded as lying within the Corradigbee Formation. The diverse fauna (with updated identifications, from Hunt and Young 2010, 2011 and additional material figured in Young et al. 2010) includes the thelodontid *Turinia*? cf. *T. hutkensis*; acanthodians:

climatiid gen. et sp. indet., diplacanthiform? gen. et sp. indet., *Tareyacanthus* cf. *T. magnificus* and *Watsonacanthus*? sp.; sarcopterygians: *Gyroptychius*? *australis*, two new taxa of osteolepiforms, and an indeterminate onychodontid?; arthrodire placoderms: *Denisonosteus weejasperensis*, cf. *Denisonosteus* sp. nov., cf. *Coccosteus* sp., and *Edgellaspis gorteri* (a new arthrodire described by Hunt and Young 2011); and the antiarch placoderms *Sherbonaspis hillsi*, cf. *Sherbonaspis* sp. nov., and *Monarolepis verrucosa*. An early Middle Devonian (early to mid Eifelian) age is now ascribed to this fauna, which is designated macrovertebrate (MAV) assemblage 3 in the scheme proposed by Young (1993, 2007).

EARLY DEVONIAN STRATIGRAPHY AROUND WINDELLAMA

Bindook Group

Tangerang Formation (Dkt on Fig. 2)

Jones et al. (1986) illustrated a variety of macrofossils from the lower part of the Tangerang Formation including the encrusting tabulate coral *Pleurodictyum* sp., brachiopods cf. *Nucleospira* sp. and cf. *Salopina* sp., and trilobites including cf. *Lioharpes* sp., *Crotalocephalus*? sp., *Acanthopyge*? (*Lobopyge*) sp., fragmentary proetid, scutellid and odontopleurid remains, together with the new species *Ananaspis ekphyma*. Although this fauna lacks precise age connotations, the stratigraphic correlation suggested by Jones et al. with the middle Windellama Limestone Member implies a Lochkovian age, based on the conodonts described by Mawson (1986).

Mawson and Talent (1999) described the brachiopod *Aulacella* sp. from the Tangerang Formation above the Windellama Limestone Member, and noted the occurrence of *Howellella* sp. and an indeterminate rhynchonellid from this level. Mawson (1975) listed the corals *Pleurodictyum megastoma*, *Cladopora* cf. *C. corrigia* and *Syringaxon* sp., bryozoans *Fenestella* sp. nov., *F. dargonensis* and an indeterminate trepostome, and a trilobite fauna including *Koneprusites* sp., *Acanthopyge australis*, *Leonaspis* sp., *Phacops* sp., scutellids, and *Cheirurus* (*Crotalocephalides*) *gaertneri* that suggests a Pragian age for a level about 375 m above the base of the Tangerang Formation.

Limestones in the Tangerang Formation that yield a Windellama-type conodont and fish fauna were almost certainly derived from the upper Windellama Limestone Member, which was the only level to yield fish remains (Basden et al. 2000). Other limestone pods in the Tangerang Formation, which lacked this

distinctive association, may have had a different provenance.

Windellama Limestone Member (Dktw on Fig. 2)

[Note that Ruth Mawson, John Talent and their colleagues from Macquarie University, who have studied the Windellama area in great detail over the past four decades, refer to this unit in their publications as a formation, rather than a member].

Mawson (1986) documented a sparse conodont fauna from the lower 128 m of the Windellama Limestone Member. She ascribed to this fauna a Pridolian (*eosteinhornensis* Zone) age on the basis of a single poorly preserved juvenile Pa element assigned to *Ozarkodina remscheidensis eosteinhornensis*; the other three specimens recovered (but not illustrated) from this interval are of no assistance in confirming the Pridolian age. The conodont fauna from the upper Windellama Limestone Member is much more diverse, with several age-diagnostic species. Conodonts described by Mawson from the upper 161 m of this unit include *Amydrotaxis corniculans*, *A. johnsoni*, *Belodella devonica*, *B. triangularis*, *B. resima*, *Icriodus postwoschmidtii*, *Oulodus greilingi spinosus*, *O. greilingi hirpex*, *O. aclys*, *O. spicula*, *O. tenuistriata*, *O. walliseri*, *O. sp.*, *Ozarkodina parvidentata*, *Panderodus unicostatus*, *Pedavis?* sp., *Wurmiella excavata excavata*, *W. excavata emaciata*, and *Zieglerodina remscheidensis remscheidensis*. Mawson determined that this upper part of the Windellama Limestone Member spans the *postwoschmidtii/eurekaensis* and *delta* zones of the early to middle Lochkovian (earliest Devonian). The uppermost limit of the Windellama Limestone Member is more contentious. Although Mawson suggested that the top of the unit may range as high as *pesavis* Zone, the evidence quoted in support of this relies on a new species of *Ozarkodina* (*O. parvidentata*) – which, as far as we are aware, is not known in sequence elsewhere locally – and a fragment of a Pa element “referred to *Pedavis* sp. somewhat hesitantly” (Mawson 1986:45) that elsewhere in this paper is termed cf. *Pedavis* sp. or *Pedavis?* sp. The range of *Pedavis* is, however, not restricted to the *pesavis* Zone (latest Lochkovian); the genus first appears in the late Ludlovian, and the species *P. pesavis* extends through both its nominate zone and the underlying *delta* Zone, according to Sweet (1988, Appendix B, Chart 4). Furthermore, *Zieglerodina remscheidensis remscheidensis* occurs right to the top of the QU section at Windellama; both Sweet (1988) and Mawson (1987) depict the range of this species as extending no higher than the top of the *delta* Zone. On balance, the conodont evidence

supports an age range of probably Pridolian to the top of the mid Lochkovian *delta* Zone for the Windellama Limestone Member in its type area. A *delta* zone conodont assemblage recovered from near the base of the Windellama Limestone Member (Percival and Sherwin 2008) in the Braidwood district, implies that the base of this unit is markedly diachronous.

Mawson and Talent (1999) described the following rhynchonelliform brachiopods (predominantly new taxa) from the Windellama Limestone Member: *Schizophoria antiqua erugata*, *Isorthis* cf. *I. clivosa*, *Pelecymya caperata*, *Pelecymya?* sp., *Mesodouvillina* (*Protocymostrophia*) *torosa*, *Morinorhynchus trypeter*, *Asymmetrochonetes picketti*, *Gypidula pelagica lunata*, *Machaeraria formosa*, *Hadrirhynchia?* *attinarium*, *Sphaerirhynchia?* *mastodon*, *Atrypa nieczlawiensis*, *Ambothis?* *inopsis*, *Howellella placeotextilis*, *H. alatectilis*, *H. legirupa*, *Reticulariopsis saginatus* and *Cyrtina praecedens*. Associated discinid and acrotretid brachiopods include *Schizotreta* sp. and *Opsiconidion* sp. (Brock et al. 1995).

Gastropods from the Windellama Limestone Member, mostly new species described by Mawson et al. (2002) include: *Bellerophon* sp., *Ruedemannia* (*Batteniella*) *calvata*, *Straparollus* (*Euomphalus*) sp., *Holopea?* sp., *Gyronema chico*, *Australonema parva*, *Yochelsonatia reticulata*, *Murchisonia* (*Murchisonia*) *auctor*, *Domipora laxa*, *Loxonema* sp., *Stylonema* sp., *Perneratia aristerospira*, *Subulites* (*Fusispira*) *aulakion* and *Vetotuba?* sp.

Bell et al. (2000) described the following agglutinated foraminifera from the Windellama Limestone Member: *Astrorhiza triquetra*, *Rhabdammina* sp. B, *Bathysiphon* sp., *Psammospaera cava*, *P. aspera*, *Sorosphaera confusa*, *S. tricella*, *Stegnammina cylindrica*, *Stomasphaera cyclops*, *Hemisphaerammina crassa*, *Tolypammina anguinea*, *Ammovertella* sp., *Ammovolummina bostryx*, *Serpenulina uralica* and *S. aulax*.

Parkes (in Basden et al. 2000) illustrated representative microvertebrates (fish) from the upper 161 m (Lochkovian age) of the Windellama Limestone Member, including placoderms (a variety of scale types and bone fragments comprising buchanosteids, a possible weejasperaspis and an acanthothoracid), acanthodian remains such as scales of *Nostolepis*, scales and a tooth whorl of *Gomphonchus?*, and a dentition cone assigned to *Poracanthodes*.

Murruin Formation (Dkm on Fig. 2)

GSNSW conodont sample C2334 (Percival and Sherwin 2005) from limestone clasts in a conglomerate at the base of the Murruin Formation

in Cobra Creek produced 54 identifiable conodont elements, including three specimens of *Flajsella stygia*. This species has a very restricted range in the middle part of the Lochkovian Stage of the Early Devonian, equivalent to the upper half of the *delta* Zone. However, as this sample came from clasts it provides only a maximum age that may not necessarily reflect the true depositional age of the Murrumbidgee Formation.

EARLY DEVONIAN STRATIGRAPHY AROUND LAKE BATHURST

Mulwaree Group

Bongalaby Formation (Dwb on Fig. 2)

Etheridge (1881) first described fossils from Devonian limestone at 'Bungaralaby, Lake Bathurst', including a gastropod questionably referred to *Loxonema sulculosa*, and "a mutilated specimen of *Conocardium*". Fletcher (1943) assigned the latter specimen to *C. sowerbyi*, and also described and illustrated another specimen from Tarago, south of Lake Bathurst, which he designated as the neotype of that species, to replace de Koninck's specimens occurring in black argillaceous limestone from the "Yass district" (most probably Taemas), that were destroyed in the Garden Palace fire of 1882. Another species of *Conocardium*, *C. mundulum*, was described by Fletcher (1943) based on a single specimen collected from limestone at Lake Bathurst Railway Station. Ross (1961:18) recorded corals, the dasycladacean alga *Receptaculites australis* and the bryozoan *Hemitrypa* sp. A from this area. Pedder (in Pedder et al. 1970:235) noted the presence of the compound rugose coral *Hexagonaria smithi smithi* in Emsian limestone at the junction of Limestone and Bongalaby creeks near Lake Bathurst Railway Station.

The occurrence of *Receptaculites australis* and *Hexagonaria smithi smithi* confirms the similarity in age between the limestones of the Lake Bathurst area and the Taemas Limestone of the Burrinjuck region. Conodonts recovered from limestones at several levels in the Bongalaby Formation (including the Lake Bathurst Limestone Member) during recent remapping of the Braidwood 1:100,000 mapsheet by the Geological Survey of NSW provide greater biostratigraphic precision in support of this correlation. However, in many cases, specific identifications are hindered by a combination of abrasion and fragmentation of conodont elements in a turbulent shallow marine environment, subsequent tectonic distortion and high CAI (5 or greater).

Lake Bathurst Limestone Member (Dwbl on Fig. 2)

Pa and Pb elements of a robust species of *Amydrotaxis*, close to *A. druceana*, were found in GSNSW conodont sample C2403 from the base of this unit. The Pa elements in particular appear to have been tumbled by wave or current action so that the denticles and lateral lobes of the basal cavity have been broken or eroded, thus preventing a definitive identification. Pickett (1980) noted that *A. druceana* ranged through both the *pesavis* and *sulcatus* zones of the latest Lochkovian to earliest Pragian. Elsewhere it apparently extends to the end of the Pragian (consistent with the range of the genus, which in NSW terminates in the *pireneae* Zone). GSNSW sample C2407, obtained from the upper part of the Lake Bathurst Limestone Member in the well-exposed and highly fossiliferous section along Bongalaby Creek, yielded a diverse and abundant fauna, including juvenile *Polygnathus dehiscens* or *P. perbonus*, *Ozarkodina buchanensis*, *Oz. linearis*, *Oulodus murrindalensis*, and either *Pandorinellina exigua* or *P. philipi*. This assemblage constrains the age of the sample to the *dehiscens* to *perbonus* zones of the early Emsian. The microfossils, which also include numerous fish scales and teeth, are generally broken and abraded. Burrow et al. (2010, fig. 5, K and L respectively) identified some of the acanthodian fish scales from this sample as *Cheiracanthoides wangi* and *Gomphonchus? bischoffi*. Macrofossils noted on the outcrop include the corals *Syringopora* and a very fine tabulate, possibly *Desmidopora*.

Ages of other limestones in the lower Bongalaby Formation are similar to the Pragian to early Emsian range established for the Lake Bathurst Limestone Member. In many samples, the presence of polygnathid conodont elements implies an age no older than late Pragian (*Polygnathus pireneae* Zone). The age of GSNSW sample C2526 can be restricted to the late Pragian to earliest Emsian interval (*pireneae* to *dehiscens* zones), based on the association of *Pandorinellina optima* with an undetermined polygnathid. Another sample, C2437 of comparable age, yielded specimens of *Polygnathus* (possibly *P. dehiscens*), and a few indeterminate elements of *Pandorinellina*, together with elements tentatively identified as *Ozarkodina buchanensis*.

Conodonts identified in GSNSW sample C2527 include *Pandorodus unicosatus?*, *Belodella devonica*, *Pelekysgnathus* sp., *Polygnathus perbonus*, *Pandorinellina optima* or *P. prolata*, and *Pandorinellina exigua*. *Polygnathus perbonus* (also found in the lower Taemas Limestone) indicates an early Emsian (*P. perbonus*-*P. gronbergi* Zone) age, consistent with the ranges of the associated species that extend over neighbouring zones.

GSNSW conodont sample C2404 from the base of the upper limestone sequence in the Bongalaby Formation yielded a Pa element of *Pandorinellina exigua philipi*. Elsewhere in central NSW the range of this subspecies extends from the base of the *pesavis* Zone (late Lochkovian) to the *patulus* Zone at the top of the Emsian (Farrell 2003). Also recovered from the residue were a variety of unidentified fish scales.

A quite different clastic facies assigned to the Bongalaby Formation on the Braidwood 1:100,000 mapsheet (Fitzherbert et al. 2011), comprising reddish-purple siltstone to pale greenish grey silty mudstone, contains abundant fragmentary remains of a primitive terrestrial plant comparable with *Cooksonia* sp. This material consists of fragmentary bifurcating stems, ranging in width from 2mm to 5mm, although the width is uniform in individual fragments.

Ungrouped Devonian strata

Cunningham Formation, Copperhannia Member (Dxnc on Fig. 2)

GSNSW conodont sample C1768 was obtained from a thin-bedded calcarenite in the Copperhannia Member of the Cunningham Formation, on the Blayney 1:100,000 mapsheet (Percival 2000). Identifiable conodonts included Pa elements of *Zieglerodina remscheidensis* sensu lato, Pb and other elements assigned provisionally to *Wurmiella excavata*, *Oulodus* sp., and *Panderodus?* sp. The presence of *Z. remscheidensis* indicates a Pridoli (latest Silurian) to Early Devonian age.

LATE DEVONIAN

Lambie Group

Strathaird Formation (DIs on Fig. 2)

Samples of the Strathaird Formation that were processed for conodonts failed to yield any, the residue being dominated by eroded and polished lingulide brachiopod fragments. Probably this unit accumulated very near to the shoreline, where intertidal lingulide brachiopods were continually reworked in the swash zone. Presence of the brachiopod *Cyrtospirifer* in the Strathaird Formation is further indication of a marine incursion into the otherwise predominantly fluvio-lacustrine Lambie Group. Young (2007) recognised this maximum marine incursion within the Merimbula Group of the far South Coast (a correlative of the Lambie Group) as the Ettrema–Westwood transgression. In Ettrema Creek gorge on the Moss Vale 1:100,000 mapsheet, a comparable fauna with *Cyrtospirifer* is associated with limestone containing late Frasnian (*rhenana* or *gigas* Zone) conodonts

(Pickett 1973). Conodont species present at Ettrema (identifications revised from form species described in the original report by Pickett) include *Ancyrodella curvata*, *Ancyrognathus asymmetricus*, *Apatognathus varians*, *Icriodus* sp., *Icriodus expansus*, *Palmatolepis hassi*, *Pelekysgnathus* cf. *P. planus*, *Polygnathus webbi* and *Polygnathus ettremae* [also referred to *Uyenognathus wadleighensis* by Savage 2004].

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PALAEOZOIC PALAEOONTOLOGY OF SOUTHERN TABLELANDS NSW

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Appendix

Notes on Silurian conodonts
(Y.Y. Zhen)

Kockelella sp. cf. *K. variabilis* Walliser, 1957
Fig. 4a-b

Material

A single specimen of a Pa element, from an allochthonous limestone in the Hawkins Volcanics (GSNSW conodont sample C1862), exposed in a creek east of Meringullalong locality, about 11 km NE of Boorowa and 13.5 km south of Frogmore (GR 668193 6193200, Boorowa 1:100,000 mapsheet).

Remarks

Two subspecies of *Kockelella variabilis* have been described: *K. variabilis variabilis* Walliser, 1957 and *K. variabilis ichnusae* Serpagli and Corradini, 1998. The Pa element of *K. variabilis variabilis* has a wider and branched inner-lateral process, from which the Pa element of *K. variabilis ichnusae* is mainly differentiated by having a wider platform with a distinctive rim and an unbranched inner-lateral process. The Pa element documented here has a wide platform and an unbranched inner-lateral process similar to the subspecies *ichnusae*, but the platform lacks the characteristic rim of that form, and the inner-lateral process is longer and narrower and differs from the holotype of *K. variabilis ichnusae* in bearing three denticles. It may represent a new subspecies, but given that only a sole specimen is presently known it is designated as *K. sp. cf. K. variabilis*. Serpagli and Corradini (1999) suggested an age range for *K. variabilis* extending from the late *K. crassa* Biozone (earliest Gorstian) to high in the Ludlow (basal *Polygnathoides siluricus* Biozone). However, *K. variabilis variabilis* was more recently reported from the lower Wenlock in Tibet (Wang, 2013:159-160, pl. 61, fig. 6) and *K. variabilis ichnusae* from the uppermost Wenlock of South China (Wang, 2013:160, pl. 61, figs 9-10). In New South Wales, both subspecies of *K. variabilis* were previously reported from the Bowspring Limestone Member (Ludlow, *Ancoradella ploeckensis* Biozone) and Hume Limestone Member (Ludlow, top *A. ploeckensis* Biozone to basal *P. siluricus* Biozone) of the Silverdale Formation in the Yass Basin (Link and Druce, 1972:41, pl. 3, figs 11, 12, 15, 16, text-fig. 21 (*K. v. ichnusae*); pl. 4, figs 1, 4, 5 (*K. v. variabilis*)).

Panderodus sp. nov.
Fig. 6a-s

Material

15 specimens from GSNSW conodont sample C1985 (allochthonous limestone block probably in the

Kerrawarry Formation), from abandoned limestone quarry at Jerrara Creek, approximately 6 km NW of Bungonia (GR 765575 6144050, Goulburn 1:100,000 mapsheet); three specimens from GSNSW conodont sample C1862 (allochthonous limestone in the Hawkins Volcanics), from limestone block exposed in a creek east of Meringullalong locality, about 11 km NE of Boorowa and 13.5 km south of Frogmore (GR 668193 6193200, Boorowa 1:100,000 mapsheet).

Description

A species of *Panderodus* consisting of short-based Pa and Pb elements and long-based S elements with Sb, Sc and Sd elements recognized; all elements with a deep panderodid furrow on the outer-lateral face, pronounced basal wrinkles, and a posteriorly extended base, which is more or less triangular in outline in lateral view. Pa element (Fig. 6k-l) with a basally suberect and distally reclined cusp, and a short and posteriorly extended base, cusp moderately compressed laterally, biconvex, with sharp posterior margin, a narrow and inner-laterally slightly flexed anterior margin, a deep and narrow furrow on the outer-lateral face (Fig. 6k) and a broad weak carina on the inner-lateral face (Fig. 6l); base with a straight to gently arched upper margin and a straight to slightly curved basal margin, tapering posteriorly. Pb element (Fig. 6d-e) with an erect cusp and a short base; cusp biconvex in cross section with a sharp posterior margin, a deep and narrow furrow on the outer-lateral face (Fig. 6d-e) and a less convex inner-lateral face; base extended posteriorly, triangular in outline with straight basal and upper margins. Sb element (Fig. 6f-g, n-p) laterally compressed with a long base; cusp suberect and biconvex with a sharp posterior margin and a deep and narrow furrow on the more convex outer-lateral face. Sc element (Fig. 6j, m) strongly compressed laterally with a suberect cusp and a long and posteriorly extended base; cusp with sharp anterior and posterior margins, a flat (Fig. 6m) or less convex (Fig. 6j) inner lateral face, and a furrowed and more convex outer-lateral face; anterior margin often flexed inward (Fig. 6m); base triangular in outline with a straight upper margin and a slightly curved basal margin. Sd element (Fig. 6a-c, h-i, q-s) like Sb, but with cusp distally twisted inward.

Discussion

This species differs from other known species of *Panderodus* by having a prominent posterior extension of the base particularly in the Pa and Pb elements (Fig. 6d-e, k-l). The Pb element is comparable with the M element of *Panderodus spasovi* Drygant, 1974 documented by Barrick (1974, pl. 3, fig. 13) from the upper Llandovery of Oklahoma, but other elements in the latter species lack extended bases.

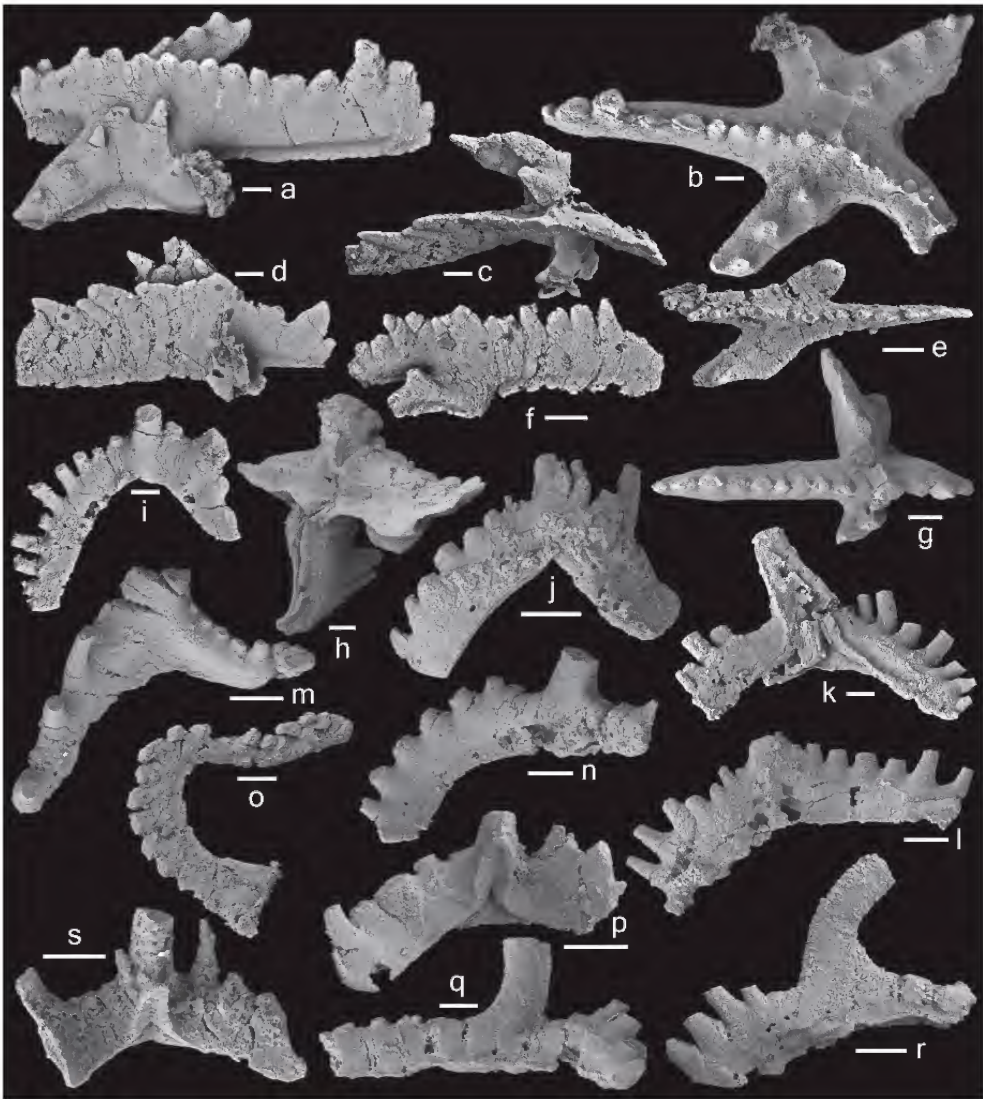


Figure 4. a-b, *Kockelella* sp. cf. *K. variabilis* Walliser, 1957; Pa element, MMMC5086, a, outer-lateral view (IY249-024), b, upper-view (IY249-002). c-h, *Kockelella maenniki* Serpagli and Corradini, 1998, Pa element, c-d, MMMC5087, c, upper view (IY249-005), d, inner-lateral view (IY249-025); e-f, MMMC5088, e, upper view (IY249-012), f, outer-lateral view (IY249-026). g, MMMC5089, upper view (IY276-020). h, MMMC5090, basal view (IY276-021). i-o, q-r, *Kockelella* sp. A; i-j, Sb element; i, MMMC5091, posterior view (IY249-018); j, MMMC5092, anterior view (IY276-018); k-n, Pb element; k, MMMC5093, basal-inner-lateral view (IY249-006); l, MMMC5094, outer-lateral view (IY276-013); m, MMMC5095, upper-inner-lateral view (IY276-014); n, MMMC5096, inner-lateral view (IY276-017); o, q-r, Sc element, o, MMMC5097, upper-posterior view (IY249-021). q, MMMC5098, inner-lateral view (IY276-015); r, MMMC5099, outer-lateral view (IY276-016). p, s, *Wurmiella excavata* (Branson and Mehl, 1933); p, Sb element, MMMC5100, posterior view (IY276-019); s, Sa element, MMMC5101, posterior view (IY277-027). a, b, from sample C1862 (limestone block in Hawkins Volcanics); all other specimens are from sample C1985 (allochthonous limestone block possibly within the Kerrawary Siltstone). Scale bar 100 μ m.

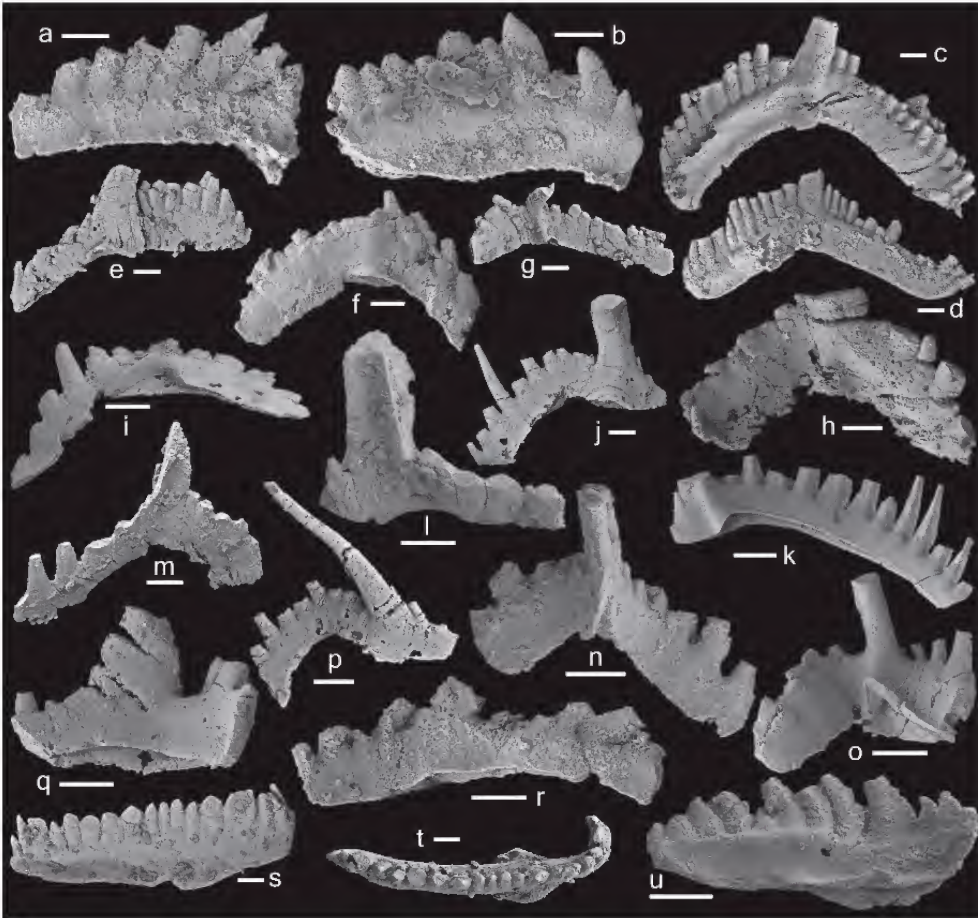


Figure 5. a-i, k-n, p-u, *Wurmiella excavata* (Branson and Mehl, 1933); a-b, Pa element; a, MMMC5102, outer-lateral view (IY276-001); b, MMMC5103, inner-lateral view (IY276-002); c-i, Pb element; c, MMMC5104, inner-lateral view (IY249-008); d, MMMC5105, outer-lateral view (IY249-011); e, MMMC5106, inner-lateral view (IY249-013); f, MMMC5107, outer-lateral view (IY276-004); g, MMMC5108, inner-lateral view (IY249-020); h, MMMC5109, inner-lateral view (IY276-003); i, MMMC5110, basal view (IY276-009); k, M element, MMMC5111, posterior view (IY277-003); l-m, Sa element; l, MMMC5112, anterior view (IY276-010); m, MMMC5113, upper-anterior view (IY249-006); n, Sb element; MMMC5114, posterior view (IY276-006); p-r, Sc element, p, MMMC5115, antero-inner-lateral view (IY249-019); q, MMMC5116, inner-lateral view (IY276-008); r, MMMC5117, inner-lateral view (IY276-011); s-u, Pa element, s-t, MMMC5118; s, outer-lateral view (IY249-023), t, upper view (IY249-009); u, MMMC5119, inner-lateral view (IY276-024); all from sample C1985 (allochthonous limestone block possibly within the Kerrawary Siltstone), except for k, from sample C1858 (Hawkins Volcanics). j, o, *Kockelella* sp. C; j, M element, MMMC5120, posterior view (IY249-017); o, Sb element, MMMC5121, posterior view (IY276-007); all from sample C1985 (allochthonous limestone block possibly within the Kerrawary Siltstone). Scale bar 100 μ m.

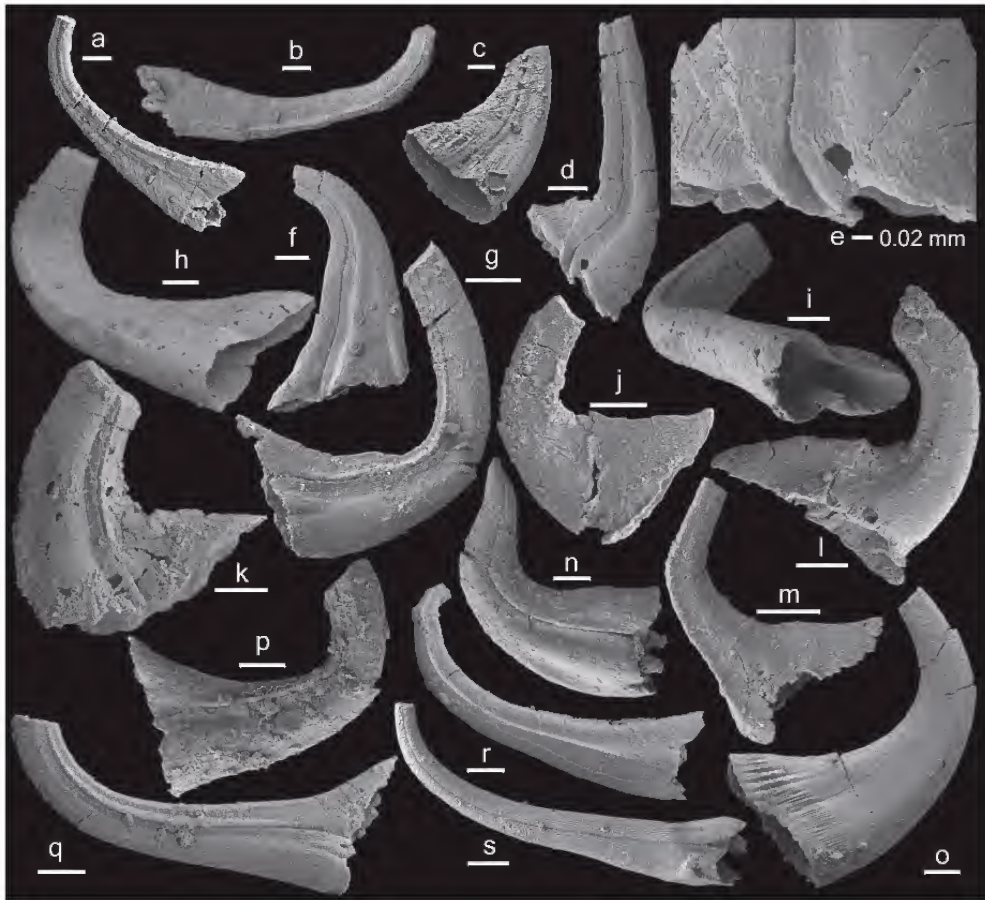


Figure 6. a-s, *Panderodus* sp. nov.; a, from sample C1862 (Hawkins Volcanics), Sd element, MMMC5126, outer-lateral view (IY249-003); b-c, Sd element, b, MMMC5145, inner-lateral view (IY277-009); c, MMMC5127, outer-lateral view (IY249-022); d-e, Pb element, MMMC5131, d, outer-lateral view (IY277-004), e, outer-lateral view, close up showing basal wrinkles and panderodid furrow (IY277-005); f-g, Sb element; f, MMMC5132, outer-lateral view (IY277-007); g, MMMC5133, outer-lateral view (IY277-006); h-i, Sd element, MMMC5134, h, inner-lateral view (IY277-013), i, antero-basal view (IY277-012); j, m, Sc element; j, MMMC5135, inner-lateral view (IY277-022); m, MMMC5136, inner-lateral view (IY277-026); k-l, Pa element; k, MMMC5137, outer-lateral view (IY277-024); l, MMMC5138, inner-lateral view (IY277-025); n-p, Sb element; n, MMMC5139, outer-lateral view (IY277-010); o, MMMC5140, inner-lateral view (IY277-011); p, MMMC5141, lateral view (IY277-015); q-s, Sd element; q, MMMC5142, outer-lateral view (IY277-020); r, MMMC5143, inner-lateral view (IY277-018); s, MMMC5144, outer-lateral view (IY277-017). All specimens (except for a) from sample C1985 (allochthonous limestone block possibly within the Kerrawary Siltstone). Scale bar 100 μ m unless otherwise indicated.

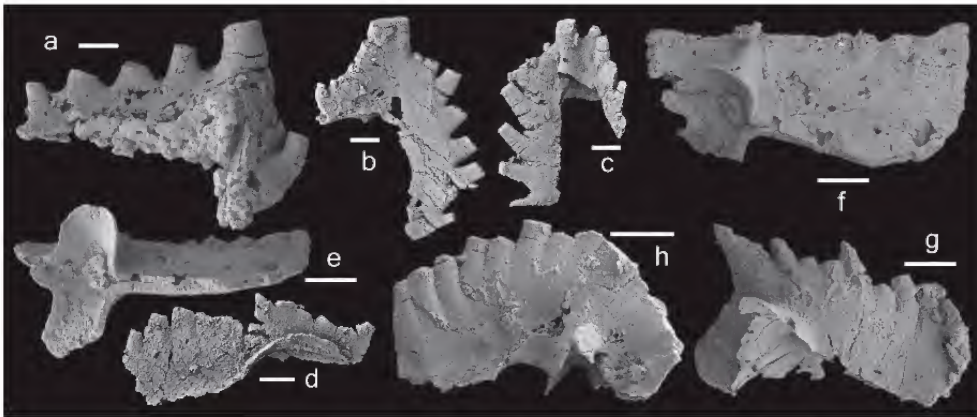


Figure 7. a-c, *Kockelella* sp. B; a, Pa element; MMMC5128, posterior view (IY276-015); b-c, Sb element; b, MMMC5129, anterior view (IY249-014); c, MMMC5130, posterior view (IY249-016). d-h, *Ozarkodina* sp.; from sample C1985 (allochthonous limestone block possibly within the Kerrawary Siltstone); d-f, Pa element; d, MMMC5122, inner-lateral view (IY249-010); e-f, MMMC5123, e, basal view (IY277-001), f, inner-lateral view (IY277-002); g-h, Pb element; g, MMMC5124, outer-lateral view (IY276-022); h, MMMC5125, inner-lateral view (IY276-023). Scale bar 100 μ m.

Octopus kapalae, sp. nov.: A New Species of *Octopus* from South-eastern Australia

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Mitchell, D.R. and Reid, A. (2017). *Octopus kapalae*, sp. nov.: A new species of *Octopus* from south-eastern Australia. *Proceedings of the Linnean Society of New South Wales*, **139**, 57–67.

Octopus kapalae, sp. nov. is described from preserved specimens housed in the Australian Museum, Sydney. The species is found on the edge of the continental shelf off south-eastern Australia, at depths between 176 m and 503 m. The possession of large eggs suggests the young hatch as miniature adults and do not disperse widely. The species may be endemic to the region.

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Keywords: Australia, cephalopod, mollusc, octopod, *Octopus kapalae*, taxonomy

INTRODUCTION

Over the last thirty years there has been a sizeable increase in our knowledge of octopus (Octopodidae) systematics. Most recent research on the Australian Octopodidae has focused on tropical (Norman 1992a, 1992b, 1992c, 1993a, 1993b, 1993c, 2000, 2001; Norman and Finn 2001) and southern temperate regions (Stranks 1990, 1996, 1998; Stranks and Norman 1992). Despite this, the general taxonomy of the Octopodidae worldwide remains comparatively poorly known, with many undescribed or inadequately defined species (Dunning et al. 1998; Norman and Hochberg 2005; Norman et al. 2016). Norman and Hochberg (2005) suggested a major revision of the group, giving detailed and accurate descriptions of all species.

Nominal *Octopus* spp. currently known to inhabit south-eastern Australia include: *O. australis* Hoyle 1885; *O. bulbus* Norman 2001; *O. micro*s Norman 2001; *O. pallidus* Hoyle 1885; *O. pyrum* Norman et al. 1997 and *O. tetricus* Gould 1852 (Reid, 2016). This paper describes a previously unidentified species of *Octopus* captured off the coast of south-eastern Australia. It is one of a number of undescribed species reported from the FRV ‘Kapala’ collections between 1971 and 1979. The description is based on the qualitative and quantitative analysis of preserved

specimens. The findings in this paper unveil the unique suite of morphological attributes that show that *O. kapalae*, sp. nov. differs from all other species described from this region and elsewhere.

MATERIALS AND METHODS

The sixteen specimens studied (thirteen male and three female) are housed at the Australian Museum, Sydney. Specimens were collected from the continental shelf on the FRV ‘Kapala’, between 1971 and 1979, fixed in 10% seawater/formalin and stored in 70% ethanol.

Measurements and indices follow Roper and Voss (1983) and Huffard and Hochberg (2005), except for sucker counts; these included all suckers rather than those on the basal half of the arms. Measurements obtained for each specimen include: arm length, AL (1–4); arm width, AW; calamus length, CL; egg length, EgL; free funnel length, FFuL; funnel length, FuL; gill length, GL; head width, HW; hectocotyliised arm length, HcA; ligula length, LL; mantle length, ML; mantle width, MW; sucker counts, SC (1–4, Hc); sucker diameter, SD; spermatophore length, SpL; spermatophore width, SpW; total length, TL; and web depth, WD (A–E). Indices were derived from these data as described in the Appendix. Indices are

NEW OCTOPUS FROM SOUTHEASTERN AUSTRALIA

expressed as minimum–mean–maximum (standard deviation, SD), in millimetres. All measurements were taken from the left side of each specimen. If a structure was damaged on that side, its opposite member was used.

The digestive tract and male and female reproductive tracts of some specimens were dissected for inspection and illustration. The buccal mass was soaked in a saturated solution of potassium hydroxide (KOH) to soften the surrounding tissue for removal of the upper and lower beak and radula using forceps and a fine brush. The beak was photographed using a light microscope and, following cleaning, the radula was air-dried, gold-coated, and examined and photographed using a Zeiss Evo LS15 Scanning Electron Microscope equipped with a Robinson Backscatter detector. Spermatophores from seven males only were measured to avoid excessive damage to type material.

TAXONOMY

Octopus kapalae, sp. nov.
(Figs 1–6, Tables 1, 2)

Material examined

Holotype: ♂ 49.5 mm ML, New South Wales, east of Grafton, 29°55'S, 153°40'E to 29°48'S, 153°42'E, 375 m, 10 Oct. 1975, coll. K.J. Graham on FRV 'Kapala' K75-09-01 (AM C.559063).

Paratypes (15): New South Wales: ♂ 53.5 mm ML, east of Grafton, 29°55'S, 153°40'E to 29°48'S, 153°42'E, 375 m, 10 Oct. 1975, coll. K.J. Graham on FRV 'Kapala' K75-09-01 (AM C.476227); 3♂ 30–35 mm ML, ♀ 30 mm ML, off Port Stephens, 32°50'–49'S, 152°41'–42'E, 274 m, 6 Dec. 1978, coll. K.J. Graham, W. Rudman and P.H. Colman on FRV 'Kapala' K78-26-10 (AM C.156202); ♂ 48.5 mm ML, off Sydney, 32°57'S, 152°35'E, 503 m, 1 Nov. 1972, coll. K.J. Graham on FRV 'Kapala' K-06-18 (AM C.476333); ♂ 35 mm ML, east of Norah Head, 33°33'S, 151°59'E to 33°28'S, 152°04'E, 384 m, 26 May 1976, coll. K.J. Graham on FRV 'Kapala' K76-07-01 (AM C.476325); ♂ 37 mm ML, off Sydney, 33°36'–44'S, 151°57'–52'E, 384 m, 13 Oct. 1976, coll. K.J. Graham on FRV 'Kapala' K76-16-02/3 (AM C.476316); ♀ 25 mm ML, 33°46'S, 151°43'E, 96 fathoms [176 m], 5 Dec. 1977, coll. FRV 'Kapala' K77-23-01 (AM C.476314); ♂ 48.5 mm ML, off Broken Bay, NSW 33°47'–41'S, 151°48'–51'E, 348 m, 25 Jul. 1979, coll. K.J. Graham on FRV 'Kapala' K79-09-03 (AM C.476230); 4♂ 36.0–42.0 mm ML, 30 ml [48.28 km] SSE of Sydney, 34°15'20'S,

151°25'21''E, 247 m, 28 Jun. 1971, coll. K.J. Graham on FRV 'Kapala' K71-10-02 (AM C.476226); ♀ 31 mm ML, off Port Kembla, 34°24'S, 151°19'E, 278 m, 13 Dec. 1978, coll. K.J. Graham and W.F. Ponder on FRV 'Kapala' K78-27-08 (AM C.476311).

Diagnosis

Small to medium-sized species; ventro-lateral mantle ridge incomplete. Arm formula usually $2>3>4>1$ or $2>3>1>4$ in both sexes. Funnel organ W-shaped. Gills with seven lamellae per demibranch. Suckers medium-sized with some slightly enlarged from pairs 10–15, on arms 2 and 3 in both sexes (slightly larger in males). Hectocotylus small (5.8–9.2% of hectocotylised arm length), cylindrical, and dorso-ventrally flattened. Pigmentation: randomly scattered, dark orange papillae on the dorsal mantle, around eyes and on the dorsal surfaces of the arms (preserved specimens). Large papilla over each eye.

Description

The following description is based on the examination of thirteen male and three female specimens. Counts and measurements for individual animals are given in Tables 1 and 2.

Small to medium-sized species; ML males 30–40.3–53.5 (SD, 7.3), females 25–28.7–31 (SD, 3.2). Mantle round, slightly elongate to ovoid, saccular, with firm muscular walls; MWI males 43–61.6–87 (SD, 11.8), females 71–80.9–92 (SD, 10.4) (Figs 1a and 1b). Head narrow; HWI males 33–46.2–61 (SD, 8.7), females, 53–59.5–63 (SD, 5.5). Eyes moderately prominent. Funnel-organ W-shaped; thick, fleshy (Fig. 2a); median and lateral limbs similar length. Arms long, slender, differ in relative lengths, in both sexes; arm formula usually $2>3>4>1$ or $2>3>1>4$ in both sexes (variable, but lateral arms always longer than dorsal and ventral arms). Second arm usually longest; ALI2 males 263–327.9–417 (SD, 42.9), females 306–403.7–528 (SD, 113.2). Third right arm of males hectocotylised, shorter than the opposing third arm; HcAI 221–260.3–340 (SD, 38.0) v. OAI 68–78.1–84 (SD, 5.8). All arms approximately equal width; AWI males 15.1–17.9–22.0 (SD, 2.4), AWI

Table 1 (NEXT PAGE) Measurements (mm), counts and indices for 13 male *Octopus kapalae*, sp. nov. For definitions of counts, measurements and indices, see Appendix. Indices are shown in brackets. Missing values are indicated by a dash (–).

* Specimen (AM C.476226) missing several arms, each severed at outer rim of web.

	Holotype AM C.559063	Paratype AM C.156202	Paratype AM C.156202	Paratype AM C.476325	Paratype AM C.156202	Paratype AM C.476226	Paratype AM C.476316	Paratype AM C.476226	Paratype AM C.476226	Paratype AM C.476226*	Paratype AM C.476333	Paratype AM C.476230	Paratype AM C.476227
TL	205	153	154	133	160	173	200	165	186	185	191	215	241
ML	49.5	30	34	35	35	36	37	37.5	37.5	42	48.5	48.5	53.5
MW	30 (61)	26 (87)	26 (76)	15 (43)	26 (74)	22 (61)	23 (62)	23.5 (63)	23 (61)	23.5 (56)	23.8 (49)	27 (56)	28 (52)
HW	20.5 (41)	18.3 (61)	20.5 (60)	13.5 (39)	17.6 (50)	19.4 (54)	18 (49)	18.5 (49)	17 (45)	17 (40)	16 (33)	18 (37)	22 (41)
FuL	17 (34)	13 (43)	14.5 (43)	13.6 (39)	14 (40)	17 (47)	19.3 (52)	16 (43)	17 (45)	20 (48)	18.3 (38)	18 (37)	20 (37)
FFuL	11 (22)	7 (23)	7.5 (25)	5.5 (16)	6.3 (18)	7.4 (21)	8 (22)	7.5 (20)	9 (24)	9 (21)	8.5 (18)	12 (25)	13 (24)
WDA	18.5	18	18.5	11.1	15	14.5	16	15	17	-	20	17	22
WDB	25(15)	21	21.5	12.8	19	18	20	22.5	17	-	22.8	23	26
WDC	25	24	22.1	14.1	18.5	22 (17)	22 (16)	21.5	20	24	28.3 (20)	27 (19)	33 (18)
WDD	22	25.5 (20)	25 (20)	15 (16)	21 (18)	20	19	23 (17)	19	30 (22)	27	23	26
WDE	21	19	17.5	12.8	14	17.5	16	16	23 (18)	21	22.4	18	21
WF	B=C>D>E>A	D>C>B>E>A	D>C>B>A>E	D>C>B=E>A	D>B>C>A>E	C>D>B>E>A	C>B>D>E=A	D>B>C>E>A	E>C>D>A=B	-	C>D>B>E>A	C>B=D>E>A	C>B=D>A>E
AL1	150 (303)	109 (363)	109 (320)	81 (231)	95 (271)	110 (306)	92 (249)	99 (264)	86 (229)	-	110 (227)	116 (239)	150 (280)
AL2	152 (303)	125 (417)	114 (335)	92 (263)	116 (331)	132 (367)	140 (378)	110 (293)	117 (312)	-	145 (299)	144 (297)	182 (340)
AL3	162 (327)	128 (427)	122 (359)	96 (274)	120 (343)	124 (344)	129 (349)	134 (357)	125 (333)	138 (329)	130 (268)	140 (289)	179 (335)
HeA	127 (257)	102 (340)	101 (297)	81 (231)	100 (286)	86 (239)	103 (278)	94 (250)	85 (227)	-	107 (221)	115 (237)	139 (260)
AL4	148 (299)	114 (380)	112 (329)	85 (243)	100 (286)	100 (278)	109 (295)	111 (296)	91 (243)	125 (298)	95 (196)	130 (268)	140 (262)
AF	3,2,1,4	3,2,4,1	3,2,4,1	3,2,4,1	3,2,4,1	2,3,1,4	2,3,4,1	3,4,2,1	3,2,4,1	-	2,3,1,4	2,3,4,1	2,3,1,4
AW	9.5 (19.2)	6.6 (22.0)	6.4 (18.8)	5.3 (15.1)	7.4 (21.1)	7 (19.4)	7.5 (20.3)	6.2 (16.5)	6 (16.0)	7 (16.7)	7.3 (15.1)	7.5 (15.5)	9 (16.8)
SD	4 (8.1)	3.4 (11.3)	4.2 (12.4)	3.2 (9.1)	3.5 (10.0)	4.3 (11.9)	3.3 (8.9)	3.1 (8.3)	3.5 (9.3)	4.5 (10.7)	3.9 (8.0)	4.5 (9.3)	4.5 (8.4)
SC1	99	116	114	102	116	98	97	112	116	-	106	120	96
SC2	126	-	122	100	138	134	126	126	142	-	118	152	144
SC3	128	140	132	102	124	136	148	128	129	111	112	153	161
SCHc	95	92	90	84	86	81	88	82	76	-	84	90	99
SC4	109	120	116	76	110	98	105	104	124	110	72	145	122
GiLC	7	7	7	7	7	7	7	7	7	7	7	7	7
GL	18 (36.4)	8.5 (28.3)	9.5 (27.9)	10.6 (30.3)	9 (25.7)	9.6 (26.7)	15 (40.5)	9.4 (25.1)	12 (32.0)	17 (40.4)	13 (26.8)	18.7 (38.6)	19.5 (36.4)
LL	9.1 (7.2)	7.2 (7.1)	7.4 (7.3)	6.5 (8.0)	7.5 (7.5)	6.5 (7.6)	9.5 (9.2)	7.1 (7.5)	6.6 (7.8)	-	9.5 (8.9)	9.2 (8.0)	8.1 (5.8)
CL	2.6 (28.6)	2 (27.8)	2.2 (29.7)	2.2 (33.8)	2.5 (33.3)	2 (30.8)	3 (31.6)	2.2 (31.0)	2.3 (34.8)	-	2.5 (26.3)	3.2 (34.8)	2.1 (25.9)
SpL	-	-	-	29.5 (84.2)	-	36.3 (101)	50 (135)	42.0 (112)	49.0 (131)	-	47 (96.9)	-	38 (71.0)
SpW	-	-	-	0.7 (2.4)	-	1.0 (2.8)	1.0 (2.0)	1.0 (2.4)	1.0 (2)	-	1.0 (2.1)	-	1 (2.6)

NEW OCTOPUS FROM SOUTHEASTERN AUSTRALIA

Table 2 Measurements (mm), counts and indices for three female *Octopus kapalae*, sp. nov.

For definitions of counts, measurements and indices, see Appendix. Indices are shown in brackets.

	Paratype AM C.476314	Paratype AM C.156202	Paratype AM C.476311
TL	160	146	98
ML	25	30	31
MW	20 (80)	27.5 (92)	22 (71)
HW	15.5 (62)	19 (63)	16.5 (53)
FuL	13.7 (55)	14.2 (47)	15 (48)
FFuL	6.5 (26)	7.3 (24)	8 (26)
WDA	16.7	18.5	11.5
WDB	21 (16)	20	16.6
WDC	20	23.5	20 (21)
WDD	16	25.5 (23)	17
WDE	11.5	18.2	14.5
WF	B>C>D>A>E	D>C>B>A>E	C>D>B>E>A
AL1	104 (416)	96 (320)	70 (226)
AL2	132 (528)	113 (377)	95 (306)
AL3	116 (464)	105 (350)	82 (265)
AL4	95 (380)	85 (283)	78 (252)
AF	2,3,1,4	2,3,1,4	2,3,4,1
AW	6.8 (27.2)	6 (20.0)	6.5 (21.0)
SD	2.5 (10.0)	2.5 (8.3)	2.5 (8.1)
SC1	131	126	85
SC2	125	147	138
SC3	129	128	132
SC4	118	128	122
GiLC	7	7	7
GL	9.3 (37.2)	9.2 (30.7)	8 (25.8)
EgL	4.3 (17.2)	6.1 (20.3)	5.5 (17.7)

females 20.0–22.7–27.2 (SD, 3.9). Total number of suckers on normal arms 72–161. Hectocotyliised right arm with fewer suckers than opposite left arm; SCHc 76–87.3–99 (SD, 6.4) v. SC3 102–131.1–161 (SD, 17.0). All arms with uniserial suckers from rows one to four, remaining sucker rows biserial. Normal sucker diameter small; ASIn males 8.0–9.7–12.4 (SD, 1.5), females 8.1–8.8–10.0 (SD, 1.7). Largest suckers occur between rows 10–15 on arms 2 and 3; slightly larger in males than females. Web depth moderate; WDI males 15–18.8–22 (SD, 2.0), females 16–19.8–23 (SD, 3.5); WF variable (Tables 1 and 2), with dorsal and ventral webs shallower than lateral webs. Gills moderate to large; GLI males 25.1–31.9–40.5

(SD, 5.9), females 25.8–31.2–37.2 (SD, 5.7) with seven lamellae per demibranch.

Copulatory organ small on hectocotyliised arm, LLI 5.8–7.7–9.2 (SD, 0.9), cylindrical and dorso-ventrally flattened, terminating in a blunt point. Ligula groove lacks clear transverse grooves. Spermatophore groove well developed; calamus distinct; CaLI 25.9–30.7–34.8 (SD, 3.1) with inverted V-shaped distal margin and deep median groove (Fig. 2b).

Digestive tract: typical *Octopus* digestive tract (Fig. 2c). Large buccal mass with pair of medium-sized anterior salivary glands joined by salivary ducts to posterior portion of buccal mass; posterior salivary glands triangular. Narrow oesophagus followed by crop diverticulum; stomach wide. Spiral caecum connected by two ducts to large digestive gland; ink sac embedded in digestive gland surface. Intestine long, curved, ending in muscular rectum. Beak strong; upper beak with prominent rostrum and small hood (Fig. 3a), lower beak with large crest and thickened wings (Figs 3b and 3c). Radula with seven teeth in transverse rows (Fig. 4a). Rhachidian tooth with 1–2 symmetrical lateral cusps (Figs 4a and 4b) migrating from medial to lateral position over six rows. First lateral teeth narrow with single cusp displaced towards second lateral teeth. Second lateral teeth with large pointed cusp displaced toward midline of radula ribbon (Fig. 4c). Marginal plates small, flat, rectangular (Fig. 4a).

Male reproductive tract: testis small, broad in mature males; vas deferens narrow, long, highly coiled and wrapped in membranous sac, opens into long spermatophore gland with distinct recurved coil; accessory gland robust, reflexed distally (Fig. 5a). Spermatophoric gland and accessory gland opening into spermatophore storage sac. Blunt appendix at junction of spermatophore storage sac and spermatophoric ducts. Terminal organ short, tubular; diverticulum spherical (Fig. 5a). Spermatophores long and narrow; SpLI 71.0–104.4–135.0 (SD, 23.4); SpWI 2.0–2.3–2.8 (SD, 0.3) (Fig. 5b). Up to three well-developed spermatophores in storage sac of mature males. Spermatophore has large number of sperm chord whorls (54 in the illustrated specimen), short midsection and a very long cap thread. Oral cap with ill-defined internal structure (Fig. 5c).

Female reproductive tract: large ovary with two oviducts protruding anteriorly, each with oviducal gland (Fig. 5d). Eggs relatively large and cylindrical; EgLI 17.2–18.4–20.3 (SD, 1.7).

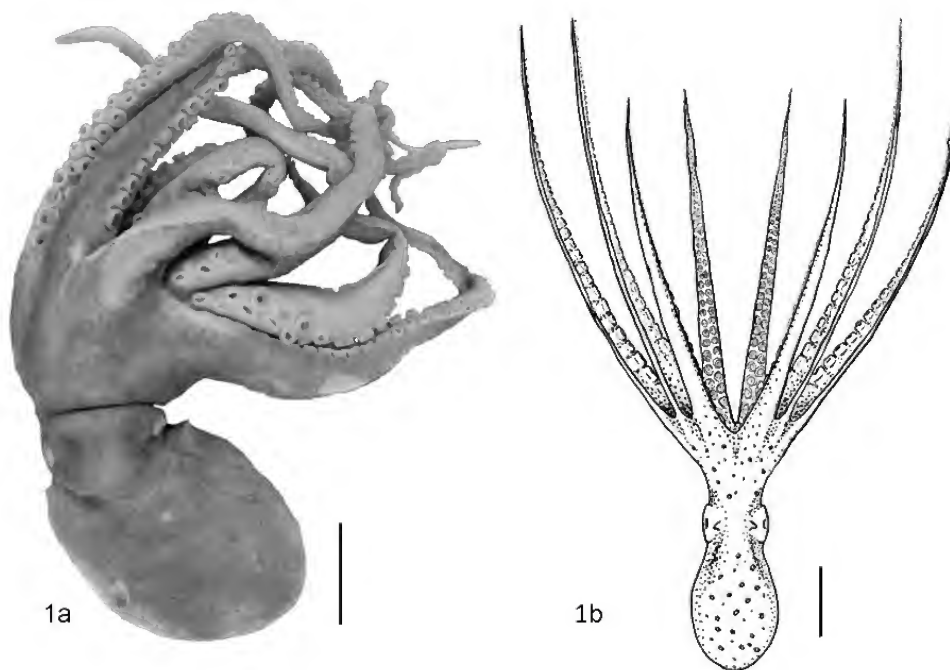


Figure 1. *Octopus kapalae*, sp. nov.: (a) photograph of holotype ♂ 49.5 mm ML (AM C. 559063), dorsal view, scale bar 2 cm; (b) stylised dorsal view, scale bar 2 cm.

Integument: colour in life unknown. Colour in preserved specimens varying from pinkish white to dark brown on dorsal surface and from cream to brownish purple ventrally. Skin relatively smooth in texture, however, dorsal surfaces of mantle, head and arms covered with low papillae of varying sizes that are more concentrated on the mantle, posterior to eyes and at the basal region of the arms. Papillae appear as distinctive orange spots in preserved specimens with larger papillae forming a bumpy texture on the integument (Figs 1a and 1b). One large papilla dorsal to each eye.

Type locality

Australia, New South Wales, east of Grafton, 29°55'S, 153°40'E to 29°48'S, 153°42'E.

Distribution

Edge of the continental shelf off the coast of south-eastern Australia. Depth range 176–503 m (Fig. 6).

Etymology

The species name, *kapalae*, is derived from the

NSW Fisheries vessel name, FV 'Kapala' from which all the specimens described here were obtained. Gender feminine.

Remarks

Within the Octopodidae, this taxon has closest affinities with the genus *Octopus* Cuvier, 1797, as defined in Norman et al. (2016:40): in having arms ~3–5 times the mantle length, lateral arms longer than the rest, and with deepest webs, and in possessing two series of arm suckers, with those on the lateral arms larger (albeit slightly) than those on the dorsal and ventral arms, and a W-shaped funnel organ. The number of gill lamellae is within the range given for the genus. However, *O. kapalae* appears to lack the conspicuous diamond arrangement of primary papillae on the mantle, characteristic of *Octopus*, and has one large papillae above each eye. It is not possible to determine whether the absence of these traits is due to the nature of preservation. In addition, the skin lacks the distinct patch and groove system that forms a reticulate pattern that is typical in *Octopus*. In contrast, the skin in *O. kapalae* is smooth, with distinctive scattered papillae. Until the octopodid

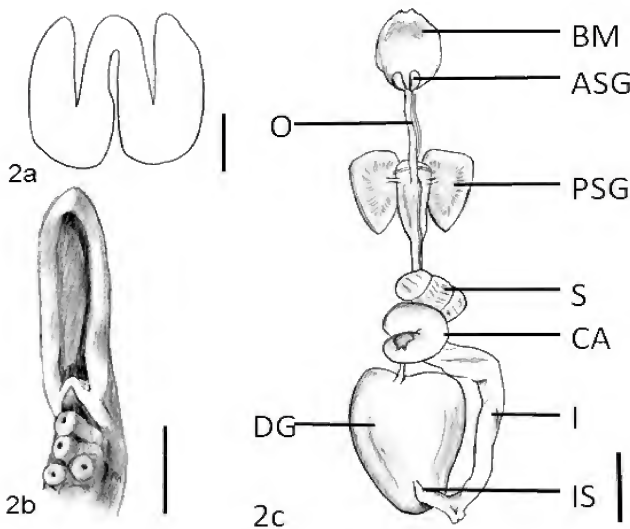


Figure 2. *Octopus kapalae*, sp. nov.: (a) paratype ♂ 37.5 mm ML (AM C.476226), funnel organ, scale bar 4 mm; (b) paratype ♂ 53.5 mm ML (AM C.476227), hectocotylus, scale bar 3 mm; (c) paratype ♂ 37 mm ML (AM C.476316), digestive tract, scale bar 1 cm. ASG, anterior salivary gland; BM, buccal mass; CA, caecum; DG, digestive gland; I, intestine; IS, ink sac; O, oesophagus; PSG, posterior salivary gland; S, stomach.



Figure 3. *Octopus kapalae*, sp. nov.: (a) paratype ♂ 53.5 mm ML (AM C.476227), upper beak lateral view, scale bar 5.5 mm; (b) lower beak lateral view, scale bar 2.8 mm; (c) lower beak ventral view, scale bar, 2.8 mm.

genera are better defined, *O. kapalae* is described among the taxa recognised as 'unplaced *Octopus*' as designated in Norman et al. (2016). Its correct generic placement can only be properly determined following a comprehensive phylogenetic analysis of *Octopus*, preferably including both morphological and molecular characters. Unfortunately, as far as we are aware, no tissue suitable for sequencing is currently available for *O. kapalae*. The specimens studied here were all originally formalin-fixed, thus not suitable for molecular examination using currently available techniques.

A combination of characters distinguish *O. kapalae* from the six other nominal *Octopus* species known to inhabit the coast of south-eastern Australia (see Introduction). These include: the W-shaped funnel organ, seven gill lamellae, a skin pattern of low orange papillae and a large papilla over each eye, an incomplete ventro-lateral mantle ridge, an arm formula usually $2>3>4>1$ or $2>3>1>4$ and a cylindrical, dorso-ventrally flattened ligula.

Octopus australis differs from *O. kapalae* in possessing a V-shaped funnel organ and a relatively shorter and more robust club-like hectocotylus, with minute papillae along the groove that are absent in *O. kapalae* (Tait 1982; Stranks and Norman 1992).

Octopus kapalae is similar to *O. bulbosus* but the hectocotylised arm of *O. bulbosus* differs from that of *O. kapalae* in relative length (OAI 56 v. 68–84) and the two taxa differ in ligula morphology, with that of *O. bulbosus* (and in giving the species its name) being very swollen and bulb-like. (To ensure this was indeed the case, an *O. bulbosus* paratype (MV F.87068) was examined to confirm this difference.) The spermatophores have 24 sperm cord whorls compared with >50 in *O. kapalae*. The first pair of arms are the longest in *O. bulbosus*, rather than the second or third pairs

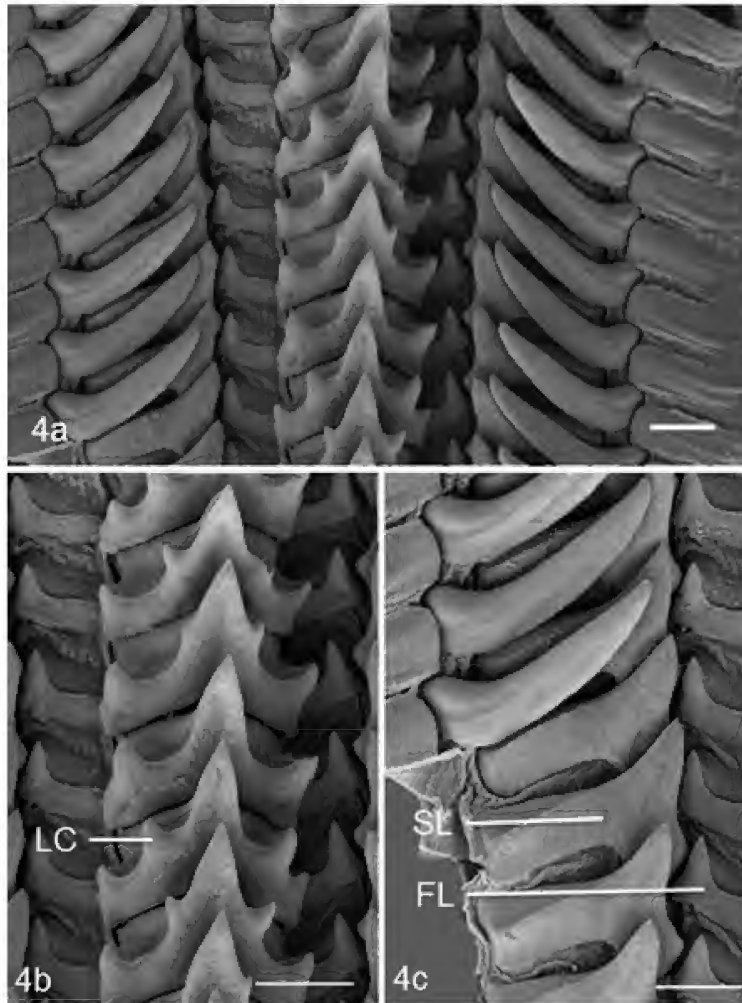


Figure 4. *Octopus kapalae*, sp. nov.: (a) paratype ♂ 53.5 mm ML (AM C.476227), transverse view of unused portion of radula ribbon, scale bar 100 µm; (b) enlargement of rhachidian tooth row, scale bar 100 µm, LC, lateral cusp; (c) enlargement of lateral teeth, scale bar 100 µm, FL, first lateral teeth; SL, second lateral teeth.

in *O. kapalae*, and are 4.9–5.6× the mantle length, while in *O. kapalae* the longest arms are usually less than 5× the mantle length. The number of arm suckers (~190) is much greater than that of *O. kapalae*, which has a maximum of 161 in the examined specimens. The rhachidian tooth of *O. bulbus* has 2–3 lateral cusps on each side (Norman 2001), as opposed to 1–2 in *O. kapalae*.

Octopus micros is a pygmy octopus, smaller than *O. kapalae* (maximum ML 25.0 v. 57.5). The arms

are approximately equal length in *O. micros*. The colouration differs between these species, with *O. kapalae* lacking the white spots and diamond shaped pattern of papillae on the dorsal mantle of *O. micros* (Norman 2001).

Octopus pyrum has a pear-shaped ligula with a distinct spermatophore guide bordered by flattened papillae or digits of skin, which clearly distinguishes it from *O. kapalae*. Several traits of *O. pyrum* are absent in *O. kapalae*, including a lateral ridge, obviously

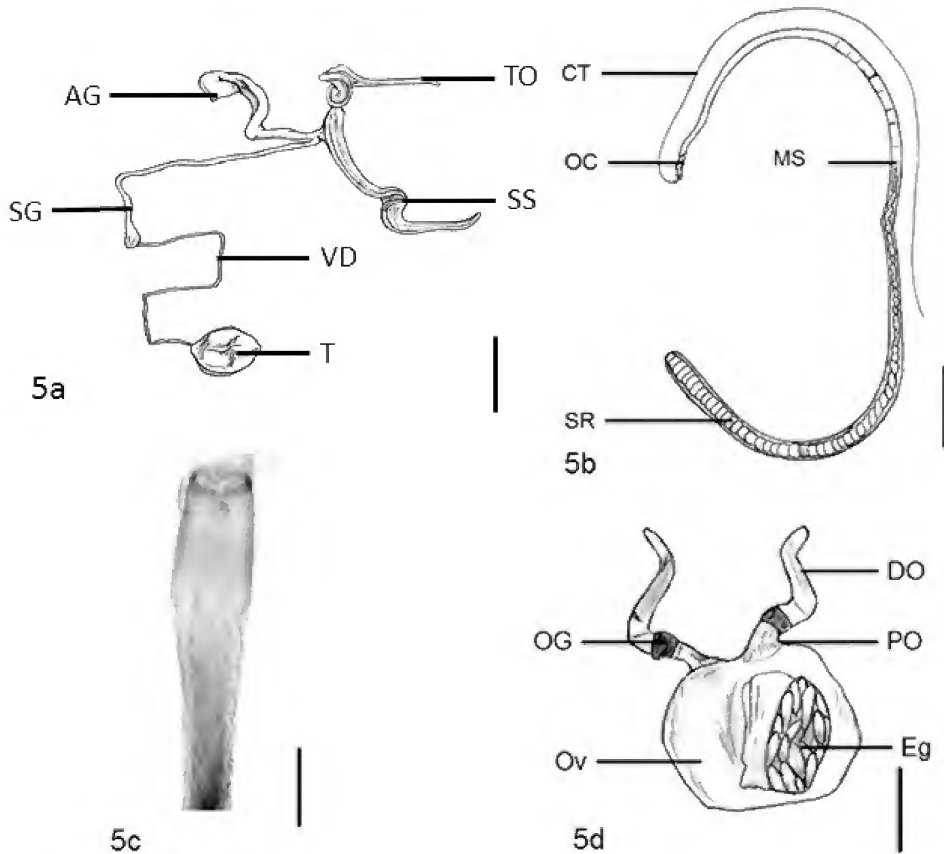


Figure 5. *Octopus kapalae*, sp. nov.: (a) paratype ♂ 37 mm ML (AM C.476316), male reproductive tract, scale bar 2 cm, AG, accessory gland; SG, spermatophoral gland; SS, spermatophore storage sac; T, testis; TO, terminal organ; VD, vas deferens. (b) spermatophore, same specimen, scale bar 5 mm, CT, cap thread; MS, mid-section; OC, oral cap; SR, sperm reservoir; (c) paratype ♂ 48.5 mm ML (AM C.476230), oral cap enlargement, scale bar, 0.5 mm; (d) paratype ♀ 30 mm ML (AM C.156202), female reproductive tract, scale bar 1 cm, DO, dorsal oviduct; Eg, eggs; OG, oviductal gland; Ov, ovary; PO, proximal oviduct.

enlarged suckers in either sex, and a distinctive transverse band of chromatophores across the medioventral mantle and tip of the funnel. In addition, cream to gold leucophores and large chromatophores over the ventral digestive gland are conspicuous in *O. pyrum* (Norman et al. 1997; Norman et al. 2016).

Octopus pallidus differs from *O. kapalae* by possession of a V-shaped funnel organ, and conspicuous sub-parallel rows of 4–6 unbranched papillae on the dorsal mantle. The skin sculpture is clearly tile-like thus differing from *O. kapalae*, and there is a faint orange stripe present along the length of the dorsal arms in *O. pallidus* that can be seen in both live and preserved specimens (Stranks 1998).

Octopus tetricus differs from *O. kapalae* in adult size (ML 140 v. 57.5), the presence of enlarged suckers in *O. tetricus*, higher sucker counts on the hectocotyliised arms (SCHc 140–160 v. 76–99), and a small ligula (LLI 1–2 v. 5.8–9.2). *Octopus kapalae* has fewer gill lamellae than *O. tetricus* (GiLC 8–9 v. 7). The eggs of *O. tetricus* are much smaller than *O. kapalae* (EgL 2–3 v. 4.3–6.1) (Stranks 1998; Norman 2000).

Species complexes from south-east Asia are disregarded by comparisons with descriptions given in Norman and Sweeney (1997). In each case, the combination of low gill lamellae count, arm formula, integumentary characters and funnel organ and

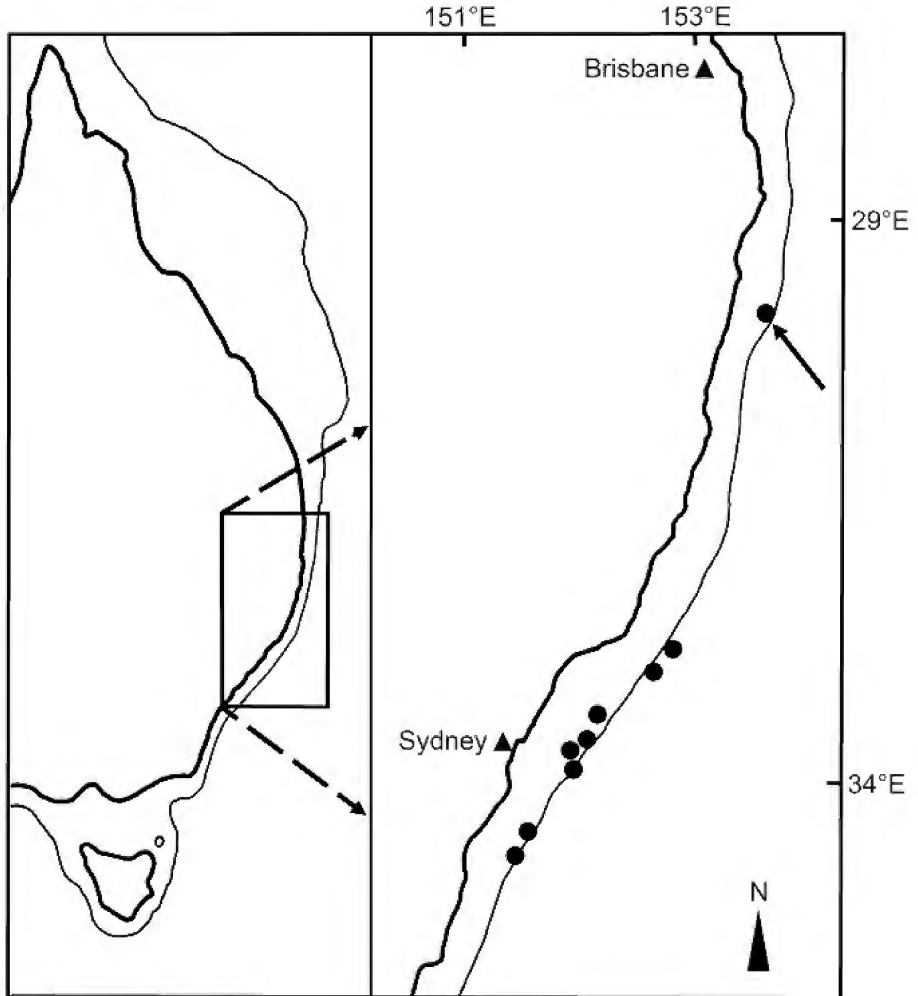


Figure 6. Distribution map of collection localities for *Octopus kapalae*, sp. nov. Line to right of continental margin represents edge of continental shelf. Arrow indicates the collection locality of the holotype.

copulatory organ morphology show that *O. kapalae* differs from each of these taxa. For the above reasons we are confident that *O. kapalae* is a species new to science.

Nothing is yet known of the ecology or behaviour of this species and the capture depth makes future observations in its natural habitat difficult. The possession of large eggs suggests that, as for other large-egged octopus species, development is probably direct, with the young probably settling soon after

hatching. This can place limitations on dispersal, suggesting that *O. kapalae* may be endemic to the region.

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NEW OCTOPUS FROM SOUTHEASTERN AUSTRALIA

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APPENDIX			
Definitions of counts, measurements and indices.			
AF	Arm Formula (arm numbers ordered from longest to shortest).	SDI	Sucker Diameter Index: diameter of the largest sucker measured across the aperture from rim to rim as a percentage of mantle length.
ALI	Arm Length Index: length of arm measured from basal-most sucker to distal tip of arm as a percentage of mantle length.	SpLI	Spermatophore Length Index: length of spermatophore as a percentage of mantle length.
ASIn	Arm Sucker Index: diameter of largest arm sucker as a percentage of mantle length.	SpWI	Spermatophore Width Index: greatest width of spermatophore as a percentage of spermatophore length.
AWI	Arm Width Index: arm width at widest point on stoutest arm as a percentage of mantle length.	TL	Total Length: measured from the tip of the longest arm to the posterior end of the mantle.
CaLI	Calamus Length Index: length of the calamus measured from the distal-most arm sucker to distal arm tip as a percentage of ligula length.	WD	Web depth from mouth to midpoint of sector (web sectors: A, dorsal to dorsal-E, ventral to ventral).
EgLI	Length of egg as a percentage of mantle length.	WDI A-E	Web Depth Index: deepest sector of web as a percentage of the longest arm length (web sectors: A, dorsal to dorsal-E, ventral to ventral).
FFuI	Free Funnel Length Index: length of free funnel portion as a percentage of mantle length.	WF	Web Formula: web sectors ordered from deepest to shallowest.
FuLI	Funnel Length Index: funnel length as a percentage of mantle length.		
GiLC	Gill Lamellae Count: number of gill lamellae per demibranch (not including the medial terminal lamella).		
GLI	Gill Length Index: length of gill as a percentage of mantle length.		
HcAI	Hectocotylied Arm Index: length of hectocotylied arm as a percentage of mantle length.		
HWI	Head Mantle Width Index: greatest width of head as a percentage of mantle width.		
LLI	Ligula Length Index: length of ligula measured from the distal-most arm sucker to distal tip of the arm as a percentage of the length of the hectocotylied arm.		
ML	Mantle Length: dorsal mantle length measured from the midpoint between the eyes to the posterior end of the mantle.		
MWI	Mantle Width Index: greatest straight-line (dorsal) width of mantle as a percentage of mantle length.		
OAI	Opposite Arm Index: length of hectocotylied arm as a percentage of its fellow arm on the opposite side.		
SC	Sucker Count: total number of suckers on normal arms.		
SCHc	Sucker Count Hectocotylus: number of suckers on hectocotylied arm of male.		

Early Devonian Conodonts from the Southern Thomson Orogen and Northern Lachlan Orogen in North-western New South Wales

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Early Devonian (Lochkovian) conodonts, recovered from carbonate intervals within the Amphitheatre Group of the northern Cobar Basin (Lachlan Orogen) and from unnamed correlative strata encountered in drillcore from Louth in the southern Thomson Orogen in north-western New South Wales, include the biostratigraphically important taxon *Caudicriodus woschmidtii*. Associated species include *Belodella resima*, *Caudicriodus* spp. indet., *Oulodus astriatus*?, *Oulodus spicula*, *Oulodus* sp., “*Ozarkodina*” *planilingua*, *Panderodus unicostatus*, *Wurmiella excavata*, and *Zieglerodina remscheidensis*. These conodont faunas provide the first biostratigraphically constrained correlations between rocks of the Cobar Basin (Cobar Supergroup) in the northern Lachlan Orogen and subsurface strata in the adjacent southern Thomson Orogen.

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KEYWORDS: Cobar Basin, Conodonts, Early Devonian, Lachlan Orogen, Thomson Orogen.

INTRODUCTION

Considerable conjecture characterises interpretations of the relationship between the southern Thomson Orogen and the Lachlan Orogen in northwestern New South Wales (e.g. Burton 2010; Cayley 2012; Glen et al. 2013). Exposure of rocks attributed to either orogen in the region north of Cobar is very limited, and outcrops of Thomson Orogen strata are rare due to thick cover comprising Cenozoic regolith units and Mesozoic sedimentary rocks of the Eromanga Basin. Information on basement geology relies heavily on geophysical surveys that penetrate the cover, with drillcores providing the only means of sampling most basement rocks. The southern Thomson Orogen is the focus of current investigations by the Geological Survey of New South Wales in collaboration with Geoscience Australia, the Geological Survey of Queensland and several universities – these studies aim to uncover

the mineral systems potential of this remote and under-explored region. One of the key objectives of these projects is to investigate and improve the age constraints for the Thomson Orogen rocks and to test correlations with better-known stratigraphic successions to the south, including that of the Cobar Basin in central NSW.

In the Louth area (Fig. 1), volcanic and metasedimentary rocks of uncertain age and association occur in sparse outcrops and mineral exploration drillholes. This area is located within the east–west zone where the southern Thomson Orogen melds with the Lachlan Orogen. In 2010, conodonts of latest Silurian to Early Devonian aspect were identified by Percival in residues from core obtained from drillhole L2 from south of Louth, leading to this detailed study. Although Early Devonian conodonts were first retrieved more than three decades ago (Pickett 1984) from limestone intersected by drillholes in the Cobar Basin adjacent to the southern

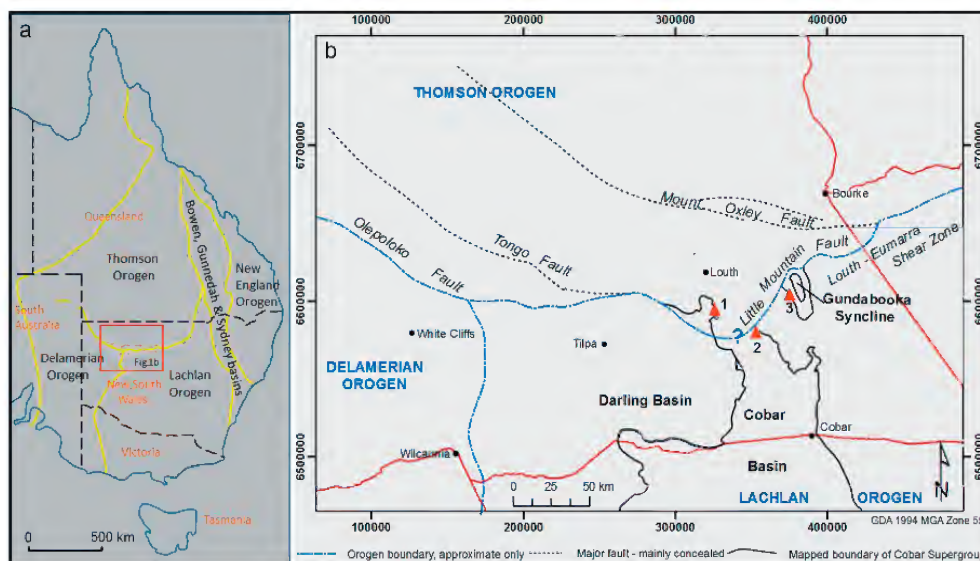


Fig. 1. Map showing the four sites (three subsurface and one surface) from where Early Devonian conodonts were collected for this study in the southern Thomson Orogen and northern Lachlan Orogen of northwestern New South Wales (background: NSW Surface Geology Map, third edition); 1, (Louth L2 drillhole); 2, (Kiri DDH K1 and DDH K6 drillholes); 3, (limestone outcrop near Stoney Tank, in the Mount Gundabooka area).

margin of the Thomson Orogen, these have not been described or illustrated. Additional sampling has provided more diverse faunas which are documented herein, supporting greater precision in regional correlations for subsurface strata in the Louth area. When integrated with geophysical and geochemical data being gathered in the Southern Thomson Project, these age constraints will be crucial for better understanding the geological and tectonic history of the southern Thomson Orogen, and its relationship with the Lachlan Orogen during the Early Devonian.

GEOLOGICAL SETTING

The Thomson Orogen (Fig. 1), one of the major geological provinces of the Tasmanides in eastern Australia, extends from north-western NSW into southwestern, central and north-eastern Queensland, with minor extensions into the northeastern corner of South Australia and the far southwest of the Northern Territory. In NSW its southern boundary against the Delamerian Orogen in the southwest and the Lachlan Orogen in the south is defined by the curved W-NW trending Olepoloko Fault in the west and the broad E-NE trending Louth-Eumarra Shear Zone in the east (Glen et al. 2013; Dunstan et al. 2016). Due to

deep weathering and covering of the Palaeozoic (and possibly older) rocks comprising the Thomson Orogen by a thick succession of Mesozoic Eromanga Basin and Cenozoic sediments, there are few surface data to constrain the exact geometry and kinematics of these major structures. Based on seismic interpretation and gravity modelling (Glen et al. 2013; Folkes 2017), the Olepoloko Fault is interpreted as a north-dipping, crustal-scale fault system. The Louth-Eumarra Shear Zone, including the Mount Oxley and Little Mountain Faults, is steep to south-dipping based on potential field gradients and modelling (Van der Wielen and Korsch 2007).

Basement rock types identified by drilling and outcrop in the Louth area include black shale, turbiditic sandstone/siltstone sequences, low-grade slate and minor limestone, with basaltic andesite and tuff, volcanoclastic rocks and gabbro/dolerite. Ages of these rocks are not well understood and are reliant on very few data as follows:

1. Poorly preserved graptolites in core from drillhole L5, sited 9 km south of Louth, were identified by Pickett (1965) as *Climacograptus* sp. and *Dicellograptus* sp. of probable Late Ordovician age.
2. Bryozoa and *Tentaculites* sp. found in limestone from drillhole L2, located 32 km south-southeast of Louth, suggested a late Silurian age (Pickett pers.

comm., cited in Brunker 1968 and Glen et al. 2010).

3. Calcareous fossil fragments within quartz-rich sandstone from drillhole L1 (collar location same as L2, but drilled towards the east) were identified as a heliolitid tabulate coral of uncertain Early Palaeozoic age in a petrographic study of Louth core by Vickery (2008).
4. Two maximum depositional ages based on U/Pb zircon provenance studies reported by Glen et al. (2010) indicate that turbidites in the L5 drillhole cannot be older than 470 Ma and volcanogenic sandstone from drillhole L2 at a depth of 139 m was most probably 422 Ma (i.e. Pridoli, latest Silurian or younger).
5. A few non-diagnostic specimens of conodonts *Ozarkodina* sp. and *Walliserodus* sp. were extracted from Burracurry Hill, 25 km northeast of Louth, by Iwata et al. (1995) as part of a study of cherts from outcrops of the Ballast Formation. They suggested an uncertain Late Ordovician age for these samples. Radiolarians were also visible but have not yet been successfully extracted using HF.

At Mount Gunterbooka, located in the Gundabooka Syncline 58 km east of Louth, (Fig. 1), Devonian sequences of the Cobar Basin (Lachlan Orogen) unconformably overlie the Early to Middle Ordovician Girilambone Group. Mount Gunterbooka is a prominent outlier of gently-dipping sandstones overlying fossiliferous siltstones and limestone (exposed at Stony Tank along the western side of the outlier). Mapping and sedimentological studies by Sharp (1992) identified a coarsening-upwards sequence from Early to Late Devonian age deposited in a prograding shelf environment.

Glen et al. (2013) suggested that the Thomson and Lachlan orogens were amalgamated or interacted around the Middle/Late Ordovician boundary interval (about 460 Ma). Current geological mapping in the region indicates that Cobar Basin stratigraphy has been confidently extrapolated approximately 80 km north of Cobar to the Kerrigundi mine area, but does not extend further north towards Louth. Improved age control for the complex rocks around Louth would help determine whether deposition was continuous from the Cobar Basin into the southern part of the Thomson Orogen during the late Silurian to Early Devonian.

MATERIAL AND SAMPLE LOCALITIES

The conodont faunas documented herein comprise 813 specimens assignable to 16 species

(including some indeterminate forms), of which 389 specimens were recovered from unnamed limestones in core from Louth L2 in the southern Thomson Orogen near Louth, and a further 190 from limestone intervals of the Amphitheatre Group encountered in drillholes Kiri DDH K6 and DDH K1 (Fig. 2). The remaining 234 specimens were obtained from a small limestone outcrop near Stony Tank (on Belah Station) in the northern Cobar Basin (Fig. 1; Table 1). The CAI of the conodonts from these localities is consistently similar, about 4 to 4.5.

Louth L2, located about 32 km south of Louth township (grid ref. 30.802657°S, 145.194924°E; Fig. 1), was drilled by the Electrolytic Zinc Company of Australasia Ltd. in 1965, and reached a depth of 570.9 m (Fig. 2). The drillcore is stored at the Londonderry Core Library of the Geological Survey of New South Wales in outer western Sydney. A total of 11 conodont samples (half core samples, about 1 kg each) were collected from calcareous intervals over the past decade and of these ten were productive, yielding a total of 389 conodont specimens (Table 1).

Getty Oil drilled Kiri DDH K6 (grid ref. 30.901510°S, 145.450495°E) and DDH K1 (grid ref. 30.903339°S, 145.452558°E) in 1984, 50 km south-east of Louth (Figs. 1, 2). Conodont samples C0986, C0987 (both DDH K6) and C0816, C0817 (both from DDH K1) collected from limestones intersected in these drillholes were initially reported by Pickett (1984, 1988), and are included in this study (Table 1). Glen et al. (2013:fig. 3) depict the location of Kiri in the northern extremity of the Cobar Basin, south of the boundary fault separating the Thomson and Lachlan orogens.

A spot sample (C0964) from a limestone lens exposed about 400 m east of Stony Tank (Belah Station) in the Mount Gunterbooka district (grid ref. 30.641012°S, 145.655903°E) of the northern Cobar Basin yielded abundant conodonts. These were initially reported by Pickett (1987) and are also incorporated in this contribution. Mathieson (2006) and Mathieson et al. (2016) described other Early Devonian (Pragian) conodonts from the vicinity of this locality.

Conodonts attributed to *Caudicriodus woschmidti* (Ziegler, 1960) from the Derriwong Group in the Trundle area (samples C0227, C0228, and C0230) and *Caudicriodus* sp. from the Yarrabandai Formation of the Bogan Gate area (sample C0001), both units of the Lachlan Orogen in central western NSW (Pickett 1975, 1992), were examined and illustrated for comparative purposes.

EARLY DEVONIAN CONODONTS FROM NORTH-WESTERN NEW SOUTH WALES

METHODS AND REPOSITORY

Limestone samples were dissolved in 10% acetic acid, and insoluble residues were separated by using sodium polytungstate solution to reduce the

residue volume for picking. Specimens illustrated were gold coated and photographed by using a mix of secondary and backscattered electrons. All photographic illustrations shown in Figures 3-7 are SEM photomicrographs of conodonts captured

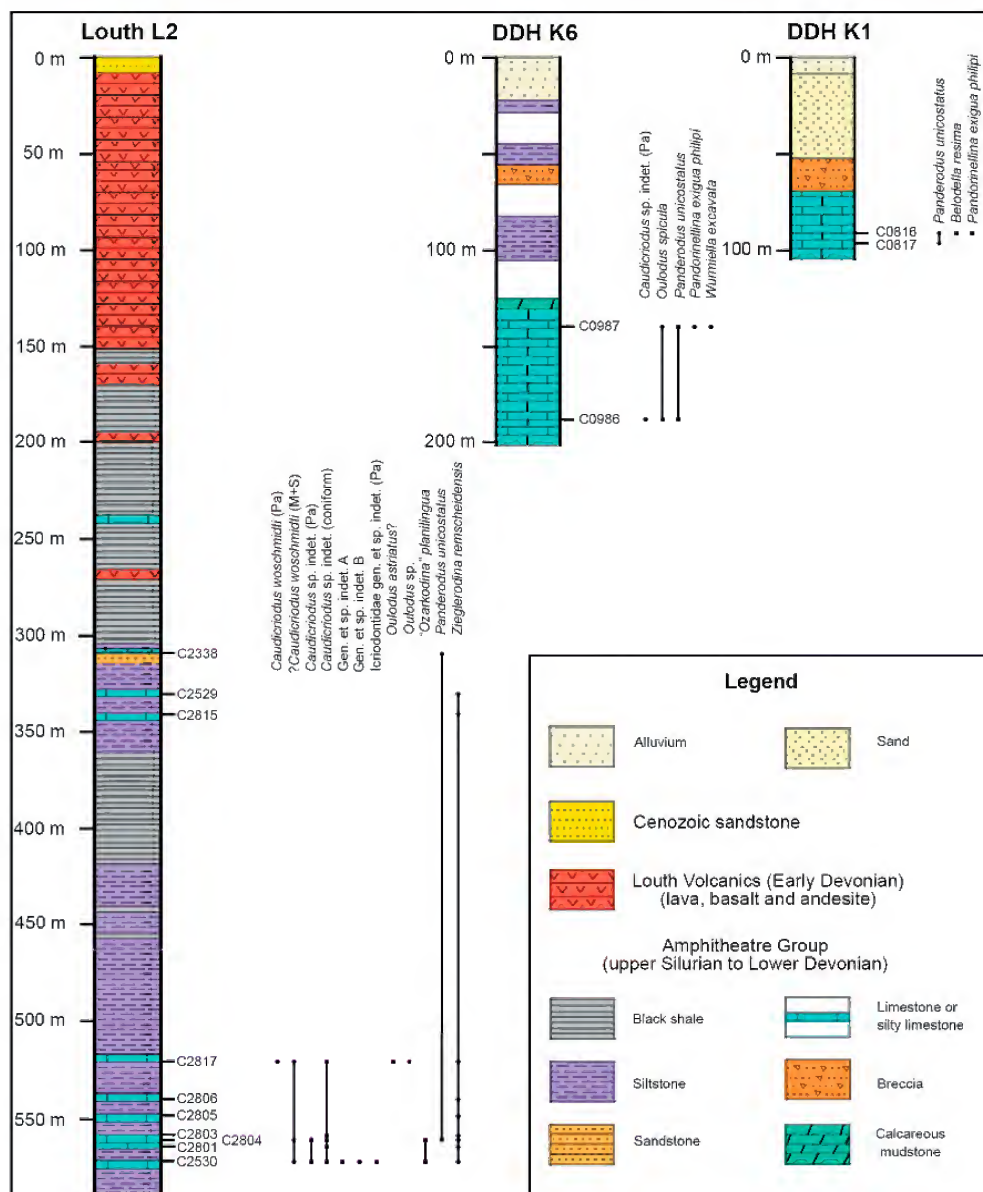


Fig. 2. Stratigraphic logs of the Lower Devonian and sampled horizons yielding conodonts in the Louth L2 drillcore, about 32 km south of Louth township in northwestern New South Wales, and the Kiri DDH K1 and DDH K6 drillholes, 50 km south-east of Louth (based on data from Lewington 1984).

Localities	Louth L2											DDH K6		DDH K1		Belah St.	
Sample numbers	C2530	C2801	C2804	C2803	C2805	C2806	C2817	C2815	C2529	C2338	C0986	C0987	C0817	C0816	C0964	Total	
Sampling depth (m) in wells	569.75-570.9	564.69-565.79	562.46-563.58	558.24-559.18	548.72-549.76	541.53-542.54	520.14-521.06	343.81-344.88	330.71-331.62	309.37-310.3	182.5-189.3	138.8-139.6	97	91.7	surface exposure		
<i>Belodella resima</i> (Philip, 1965) <i>Cauderiodus woschmidt</i> (Ziegler, 1960) (Pa element) ? <i>Cauderiodus woschmidt</i> (M and S elements) <i>Cauderiodus</i> spp. indet. (Pa element) <i>Cauderiodus</i> sp. indet. (coniform elements) Gen. et sp. indet. A (coniform) Gen. et sp. indet. B (coniform) Icriodontidae Gen. et sp. indet. (Pa element) <i>Oulodus asfriatus</i> Mathieson et al., 2016 ? <i>Oulodus spicula</i> Mawson, 1986 <i>Oulodus</i> sp. “ <i>Ozarkodina</i> ” <i>planilingua</i> Murphy and Valenzuela-Rios, 1999 <i>Pandorinellina exigua philipi</i> (Klapper, 1969) <i>Panderodus unicosatus</i> (Branson and Mehl, 1934) <i>Wurmella excavata</i> (Branson and Mehl, 1933) <i>Zieglerodina remscheidensis</i> (Ziegler, 1960)	1	2	15	3		19								1	3	1	
	1		3			1										4	
	3		3								1					5	
	15															7	
	1															54	
	1															1	
	1															1	
	1															1	
	1															2	
	1															3	
1		2														3	
1																5	
1			1							1	3	127	1	21	209	363	
29											29					29	
333	74	10	79	37	6	2	94	8	1						22	333	
813	97	12	103	40	6	2	119	8	1	1	5	161	1	23	234	813	

Table 1. Distribution of conodont species in the samples from the Amphitheatre Group and correlative units encountered in subsurface drillholes (Louth L2, Kiri DDH K6 and DDH K1), and a small surface limestone exposure exposed near Stoney Tank (Belah Station) adjacent to the southern margin of the Thomson Orogen in north-western New South Wales.

digitally (numbers with the prefix IY are the file names of the digital images). Figured specimens (69 in total) bearing the prefix MMC (5173 to 5241) are deposited in the microfossil collection of the Geological Survey of New South Wales, housed at the WB Clarke Geoscience Centre at Londonderry in outer western Sydney.

CONODONTS FROM THE SOUTHERN THOMSON OROGEN

Conodonts from the unnamed carbonate intervals within the Amphitheatre Group encountered in Louth L2 drillhole (Table 1; Figs 3-6) include a Pa element (Fig. 3b-d) and doubtfully assigned M and S (Fig. 3j-o) elements of *Caudicriodus woschmidt*, *Caudicriodus* sp. indet. (Pa element; Fig. 3e-f), *Caudicriodus* sp. indet. (coniform elements; Fig. 4a-p), Gen. et sp. indet. A (Fig. 3p), Gen. et sp. indet. B (Fig. 4q), *Icriodontidae* gen. et sp. indet. (Pa element; Fig. 3a), *Oulodus* sp. (Fig. 5n-q), *Oulodus astriatus*? Mathieson, Mawson, Simpson and Talent, 2016 (Fig. 6a), “*Ozarkodina*” *planilingua* Murphy and Valenzuela-Rios, 1999 (Fig. 5a-b), *Panderodus unicostatus* (Branson and Mehl, 1933), and *Zieglerodina remscheidensis* (Ziegler, 1960) (see Fig. 5c-m). A well preserved specimen (Fig. 3b-d) assignable to the Pa element of *C. woschmidt* was recovered from sample C2817 from 520.14–521.06 m depth in the L2 drillhole, and supports the correlation of this fauna with the typical basal Lochkovian *Caudicriodus woschmidt* Biozone recognized worldwide. Several broken specimens (Fig. 3e-f) recovered from samples C2530 and C2804 were assigned to *Caudicriodus* sp. indet. These likely represent the Pa element of *C. woschmidt*, but lack the diagnostic posterior part. Ramiform and coniform elements tentatively assigned to the species apparatus of *C. woschmidt* were also recovered from three samples in the Louth L2 drillhole (Table 1), and are identical with those documented by Serpagli (1983:pl. 7, A-D, H, I) from Europe. The Sc element (Fig. 3k-l, n-o) has a single denticle on the posterior edge, and the Sb element (Fig. 3j) typically has two denticles and a sharp blade-like protoprocess on the outer-lateral side. The M element is scandodiform, with the cusp proclined and also curved posteriorly (Fig. 3m). The other biostratigraphically important species recovered from the L2 drillcore samples is “*Ozarkodina*” *planilingua*, which is characterized by having larger basal platform lobes with a small terrace compared with the associated *Z. remscheidensis*. “*Ozarkodina*” *planilingua* has a stratigraphic range from the

uppermost Přidoli to middle Lochkovian in North America and the Spanish Pyrenees (Murphy and Valenzuela-Rios 1999:text-fig. 1). In central New South Wales, “*O.*” *planilingua* has a very similar range, extending through the uppermost Přidoli (uppermost *eosteinhornensis* Biozone) to lower Lochkovian (*woschmidt* Biozone) in the Camelford Limestone at the Gap, about 10 km NE of Cummoock (Farrell 2004).

EARLY DEVONIAN CONODONTS FROM THE LACHLAN OROGEN

In the Lachlan Orogen of central NSW, conodont faunas of Early Devonian age characterized by the occurrence of *C. woschmidt* were reported from the Amphitheatre Group of the northern Cobar Basin (Pickett 1987, 1988), the White Tank Limestone

Fig. 3 (next page). a, *Icriodontidae* gen. et sp. indet., Pa element, MMC5173, from sample C2530 (Louth L2), upper view (IY310-020), b-d, *Caudicriodus woschmidt* (Ziegler, 1960). Pa element, MMC5174, from sample C2817 (Louth L2), b, outer-lateral view (IY308-012), c, upper view (IY310-022), d, close up of upper view (IY310-023). e-g, *Caudicriodus* sp. indet., Pa element, e, MMC5175, from sample C2804 (Louth L2), upper view (IY309-009); f, MMC5176, from sample C2530 (Louth L2), upper view (IY279-022). g, MMC5177, from sample C0986 (DDH K6), upper view (IY310-010). h, *Caudicriodus woschmidt* (Ziegler, 1960). Pa element, MMC5178, from sample C964 (Belah Station), upper view (IY303-001). i, *Caudicriodus woschmidt*? (Ziegler, 1960). Pa element, MMC5179, from sample C964 (Belah Station), upper view (IY303-002). j-o, ?*Caudicriodus woschmidt* (Ziegler, 1960). j, Sb element, MMC5180, from sample C2804 (Louth L2), outer-lateral view (IY309-001); k-l, Sc element, MMC5181, from sample C2817 (Louth L2), k, inner-lateral view (IY308-015), l, close up showing surface striation (IY308-016); m, M element, MMC5182, from sample C2817 (Louth L2), outer-lateral view (IY308-023); n-o, Sc element, n, MMC5183, from sample C2530 (Louth L2), anterior view (IY279-024); o, MMC5184, from sample C2804 (Louth L2), outer-lateral view (IY309-002). p, Gen. et sp. indet. A, coniform (asymmetrical, short-based) element, MMC5185, from sample C2530 (Louth L2), outer-lateral view (IY308-023). Scale bar 100 µm unless otherwise indicated.





Legend on next page

Fig. 4 (preceding page). a-p, *Caudicriodus* sp. indet. (coniform elements); a-d, Sa element; a, MMMC5194, from sample C2804 (Louth L2), posterior view (IY309-003); b, MMMC5195, from sample C2530 (Louth L2), posterior view (IY279-029); c, MMMC5196, from sample C2530 (Louth L2), posterior view (IY279-026); d, MMMC5197, from sample C2530 (Louth L2), upper view (IY280-002); e-i, Sb element; e, MMMC5198, from sample C2530 (Louth L2), outer-lateral view (IY280-003); f, MMMC5199, from sample C2817 (Louth L2), posterior view (IY308-021); g, MMMC5200, from sample C2804 (Louth L2), outer-lateral view (IY309-005); h, MMMC5201, from sample C2804 (Louth L2), inner-lateral view (IY309-004); i, MMMC5202, from sample C2804 (Louth L2), inner-lateral view (IY309-007); j-m, Sc element; j, MMMC5203, from sample C2804 (Louth L2), outer-lateral view (IY309-006); k, MMMC5204, from sample C2817 (Louth L2), upper view (IY308-020); l-m, MMMC5205, from sample C2530 (Louth L2), l, inner-lateral view (IY279-031), m, close up showing surface striation (IY279-032); n-o, Sd element; n, MMMC5206, from sample C2817 (Louth L2), basal-posterior view (IY308-017); o, MMMC5207, from sample C2817 (Louth L2), posterior view (IY308-018); p, Sc element, element, MMMC5208, from sample C2817 (Louth L2), outer-lateral view (IY308-022). q, Gen. et sp. indet. B, S? element, MMMC5209, from sample C2530 (Louth L2), inner-lateral view (IY279-028). r-v, *Panderodus unicostatus* (Branson and Mehl, 1933), all from sample C964 (Belah Station). r, qg element, MMMC5210, outer-lateral view (IY303-017); s, qa element, MMMC5211, outer-lateral view (IY303-010); t, qa element, MMMC5212, outer-lateral view (IY303-008); u, qg element, MMMC5213, outer-lateral view (IY303-011); v, qg element, MMMC5214, outer-lateral view (IY303-016). Scale bar 100 μ m unless otherwise indicated.

Fig. 5 (next page). a-b, "*Ozarkodina*" *planilingua* Murphy and Valenzuela-Rios, 1999; Pa element; a, MMMC5215, from sample C2804 (Louth L2), upper view (IY309-018); b, MMMC5216, from sample C2530 (Louth L2), outer-lateral view (IY279-010). c-m, *Zieglerodina remscheidensis* (Ziegler, 1960). c-d, Pa element; c, MMMC5217, from sample C2817 (Louth L2), inner-lateral view (IY308-003); d, MMMC5218, from sample C2817 (Louth L2), outer-lateral view (IY308-008); e-g, Pb element; e, MMMC5219, from sample C2817 (Louth L2), inner-lateral view (IY308-002); f, MMMC5220, from sample C2817 (Louth L2), inner-lateral view (IY308-009); g, MMMC5221, from sample C2817 (Louth L2), outer-lateral view (IY308-001); h-i, Sa element; h, MMMC5222, from sample C2817 (Louth L2), posterior view (IY308-013); i, MMMC5223, from sample C2801 (Louth L2), posterior view (IY309-010); j-k, Sc element; j, MMMC5224, from sample C2817 (Louth L2), inner-lateral view (IY308-011); k, MMMC5225, from sample C2817 (Louth L2), outer-lateral view (IY309-011); l-m, M element; l, MMMC5226, from sample C2817 (Louth L2), posterior view (IY308-006); m, MMMC5227, from sample C2804 (Louth L2), anterior view (IY309-013). n-q, *Oulodus* sp.; Sb element, n-o, MMMC5228, from sample C2817 (Louth L2), n, upper view (IY309-014), o, close up showing cross section of cusp (IY309-015); p, MMMC5229, from sample C2817 (Louth L2), anterior view (IY308-010); q, MMMC5230, from sample C2817 (Louth L2), posterior view (IY308-004); Scale bar 100 μ m.

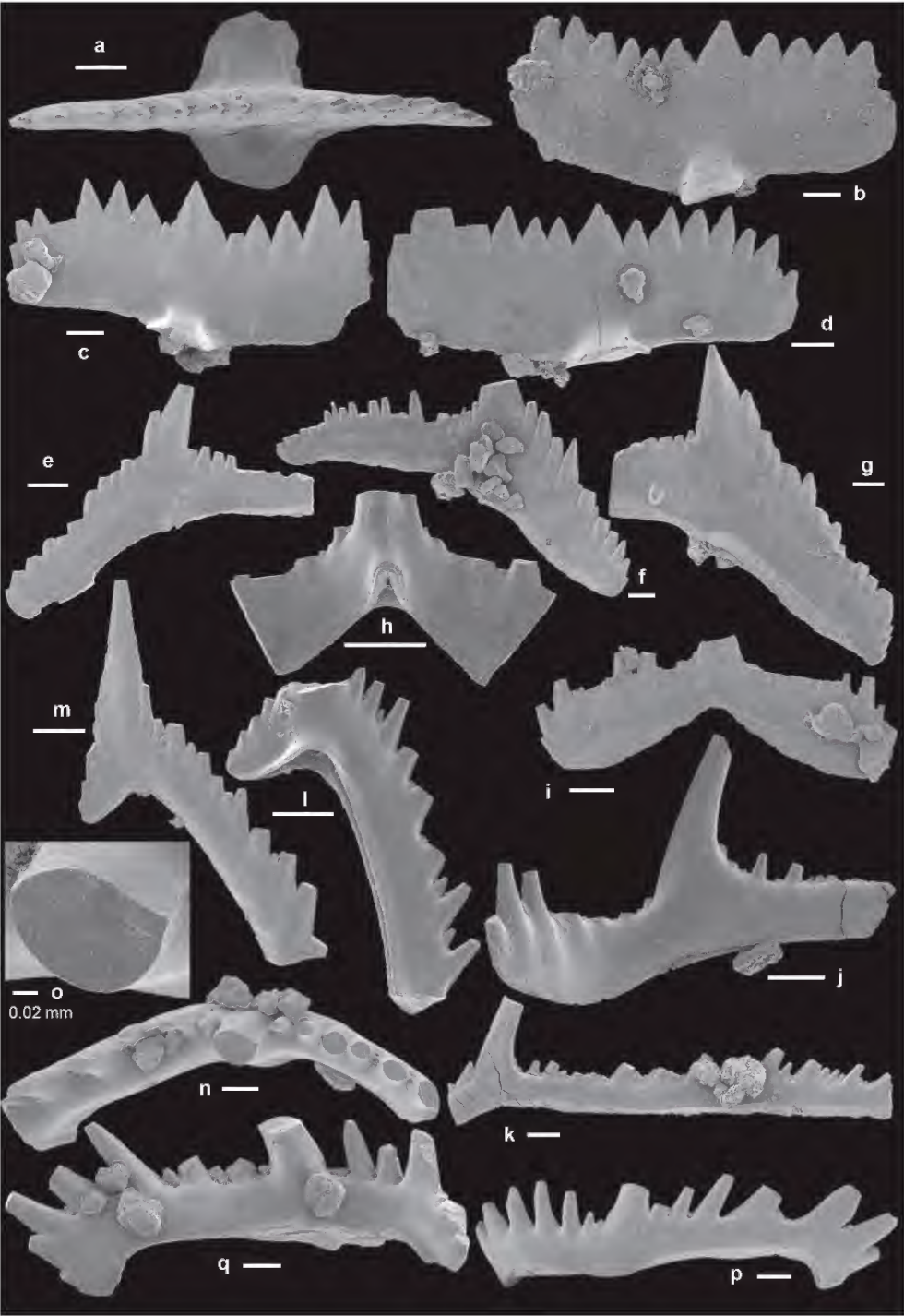




Fig. 6. a, *Oulodus astriatus*? Mathieson, Mawson, Simpson and Talent, 2016. Sa element, MMMC5231, from sample C2817 (Louth L2), posterior view (IY310-001). b, *Belodella resima* (Philip, 1965). Sc element, MMMC5232, from sample C0816 (DDH K1), inner-lateral view (IY308-006). c-h, *Wurmiella excavata* (Branson and Mehl, 1933). c-d, Pa element; c, MMMC5233, from sample C0987 (DDH K6), inner-lateral view (IY310-004); d, MMMC5234, from sample C0987 (DDH K6), outer-lateral view (IY310-005); e-f, Pb element; e, MMMC5235, from sample C0987 (DDH K6), inner-lateral view (IY310-002); f, MMMC5236, from sample C0987 (DDH K6), outer-lateral view (IY310-003); g-h, Sc element; g, MMMC5237, from sample C0987 (DDH K6), inner-lateral view (IY310-006); h, MMMC5238, from sample C0987 (DDH K6), posterior view (IY310-007). i-j, *Oulodus spicula* Mawson, 1986. i, Sb element, MMMC5239, from sample C0987 (DDH K6), posterior view (IY310-008); j, Sa element, MMMC5240, from sample C0986 (DDH K6), posterior view (IY310-011). k, *Pandorinellina exigua philipi* (Klapper, 1969). Pa element, MMMC5241, from sample C0987 (DDH K6), outer-lateral view (IY310-009). Scale bar 100 μ m.

Member of the Meryula Formation (Kopyje Group) exposed immediately S-SE of Cobar (Pickett 1980), and from the Derriwong Group exposed NW of Bogan Gate (Pickett 1975) and in the Mineral Hill – Trundle area (Pickett, 1975, 1992).

Conodonts from two samples (C0986, C0987) collected from limestone intervals intersected in the borehole Getty Oil Kiri DDH K6 and initially reported by Pickett (1988) are re-evaluated herein. The following species were recognised (Table 1):

Caudicriodus sp. indet. (Fig. 3g), *Oulodus spicula* Mawson, 1986 (Fig. 6i-j), *Pandorinellina exigua philipi* (Klapper, 1969) (Fig. 6k), *Panderodus unicostatus*, and *Wurmiella excavata* (Fig. 6c-h), with *P. unicostatus* being dominant. The only icriodiform specimen is incomplete with its posterior part broken, and is assigned to *C. sp. indet.* A prominent cusp exhibited by this specimen (Fig. 3g) indicates that it may be more comparable with *Caudicriodus postwoschmidti* (Mashkova, 1968). *Oulodus spicula*

was originally reported by Mawson (1986) from the Windellama Limestone (now Windellama Limestone Member of the Tangerang Formation – see Percival and Zhen 2017:39) of central NSW, and its association with *Caudicriodus postwoschmidti* at the type locality suggested a middle Lochkovian age (*eurekaensis* to *delta* biozones). However, later studies indicated that this species ranges into the lower Pragian (*sulcatus* Biozone; Wilson 1989; Farrell 2004). *Pandorinellina exigua philipi* is widely distributed with a stratigraphic range extending from the upper Lochkovian (*pesavis* Biozone) to upper Emsian (*patulus* Biozone). Therefore, co-occurrence of these species in the sampled interval of the DDH K6 drillcore supports a middle–late Lochkovian age for that level.

Conodonts recovered from samples C0816 and C0817, taken from a carbonate interval encountered in the nearby Getty Oil Kiri DDH K1 drillhole (Pickett, 1984), are not diagnostic of a precise age, comprising only *Belodella resima* (Philip, 1965) (Fig. 6b), *Panderodus unicostatus* and *Pandorinellina exigua philipi*, with the latter species implying a generally Early Devonian age. However, *Amydrotaxis johnsoni* was subsequently found at a comparable depth of 93.22–93.96 m in DDH K1, indicating a Lochkovian (*delta* or *pesavis* zones) age (Mawson 2006).

A closely comparable conodont assemblage to that found in L2 and Kiri DDH K6 was reported by Pickett (1987) from a unnamed limestone lens (sample C0964) of the Amphitheatre Group, exposed 400 m east of Stoney Tank (Belah Station) in the Gunderbooka district of the northern Cobar Basin. It includes *Caudicriodus woschmidti*, *Panderodus unicostatus*, and *Zieglerodina remscheidensis* with *P. unicostatus* as the dominant species (Table 1). Occurrence of *C. woschmidti* (Fig. 3h–i) in the fauna suggests an early Lochkovian age (the *Caudicriodus woschmidti* Biozone). However, samples from this area yielded a diverse conodont fauna of late Pragian age (Mathieson et al. 2016), suggesting that they were derived from a younger carbonate interval exposed in the area.

Pickett (1980:69) interpreted an early Lochkovian age (late *woschmidti* Biozone) for the White Tank Limestone Member of the Meryula Formation based on the occurrence of *Caudicriodus woschmidti*, and a late Lochkovian (*pesavis* Biozone) for the Rookery Limestone Member (also of the Meryula Formation) mainly on the occurrence of *Pedavis pesavis* and absence of *Caudicriodus woschmidti*. However, Mathieson et al. (2016) considered both units to be of Pragian age (late *sulcatus* Biozone). They reported the co-occurrence

of *Caudicriodus ampliatus* Mathieson, Mawson, Simpson and Talent, 2016 with *Zieglerodina remscheidensis*, *O. sp. cf. O. eurekaensis* (Klapper and Murphy, 1975), *Oulodus sp. cf. O. walliseri* (Ziegler, 1960), *Panderodus* spp., and *Wurmiella wurmi* (Bischoff and Sannemann, 1958) in the White Tank Limestone Member, and argued that significant compositional differences in faunas recovered from the two limestone members within the Meryula Formation were attributable to facies differences – according to Felton (1981) the White Tank Limestone Member was deposited in the forereef setting, laterally grading into the Rookery Limestone Member of the backreef facies. Alternatively, the apparent faunal differences might suggest the periodical exposure and erosion of the shallow water, reefal carbonates, which resulted in the mixing of conodont assemblages of different ages (Thomas Suttner, pers. comm. 2017).

Samples C0227–C0230 from the Derriwong Group exposed about 7 km NNE of Trundle township reported by Pickett (1975) yielded *Caudicriodus woschmidti* (Fig. 7a–g), *Wurmiella excavata*, and *Panderodus unicostatus*. A specimen likely conspecific with *C. woschmidti* but lacking the diagnostic posterior part also occurs in a sample (C0001; Fig.

Fig. 7 (next page). a–g, *Caudicriodus woschmidti* (Ziegler, 1960) from the Derriwong Group of the Lachlan Orogen in central western New South Wales; a–f, Pa element, g, Pb element; a, MMC5186, from sample C0230, juvenile specimen without denticles on the posterior process, upper view (IY310-021); b, MMC5187, from sample C0230, juvenile specimen with tendency of rudimentary denticles on the posterior process, upper view (IY310-019); c, MMC5188, from sample C0228, specimen with weakly-developed denticles on the posterior process, upper view (IY310-017); d, MMC5189, from sample C0228, specimen with well-developed denticles on the posterior process, upper view (IY310-016); e, MMC5190, from sample C0227, specimen with well-developed denticles on the posterior process, upper view (IY310-013); f, MMC5191, from sample C0227, specimen with weakly-developed denticles on the posterior process, upper view (IY310-014); g, MMC5192, from sample C0227, outer-lateral view (IY310-015). h, *Caudicriodus* sp., Pa element, MMC5193, from sample C0001, Yarrabandai Formation of the Lachlan Orogen in central western New South Wales, upper view (IY310-018). Scale bar 100 µm (specimens are illustrated at the same magnification).



7h, Table 2) originally reported by Pickett (1975) from the Yarrabandai Formation exposed NW of Bogan Gate along with *Zieglerodina remscheidensis* and *Panderodus unicostatus*. However, a spot sample from a small limestone exposure about 10 km SSW of Trundle township produced a diverse assemblage of younger age (Mathieson et al. 2016:fig. 32A-O).

It includes *Caudicriodus ampliatus*, *Eognathodus sulcatus lanei* Mathieson, Mawson, Simpson and Talent, 2016, *Ozarkodina paucidentata* Murphy and Matti, 1982, *Ozarkodina selfi* Lane and Ormiston, 1979, *Panderodus unicostatus*, *Wurmiella excavata*, and *Zieglerodina remscheidensis*, indicative of the early Pragian *sulcatus* Biozone.

CONCLUSIONS

Low diversity conodont faunas of Early Devonian age were recovered from four sites (three drill cores and one outcrop) in the vicinity of the boundary between the Thomson Orogen and the Lachlan Orogen in northwest NSW. The rare occurrence of *Caudicriodus woschmidtii* in both the Louth L2 drill core and the exposure in the Gunderbooka district indicates the presence of the *Caudicriodus woschmidtii* Biozone of Lochkovian age. Recognition of correlative units of Lochkovian age on either side of the Olepoloko Fault marking the boundary between the Thomson Orogen to the north from the Lachlan Orogen (northern Cobar Basin and Kopyje Shelf) to the south implies that the reactivation of this major fault took place no earlier than the late Early Devonian (Emsian). The study also has important ramifications for constraining the age of the Louth Volcanics, which in Louth L2 overlie the calcareous units containing Lochkovian conodont faunas. This supports the maximal U/Pb detrital zircon dating age of 422 Ma obtained by Glen et al. (2010) from volcanogenic sandstone within the volcanic succession at a depth of 139 m in drillhole L2, and indicates that the actual depositional age of this bed is slightly younger.

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Silurian Brachiopods from the Bredbo Area North of Cooma, New South Wales, Australia

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Strusz, D.L. (2017). Silurian brachiopods from the Bredbo area north of Cooma, New South Wales, Australia. *Proceedings of the Linnean Society of New South Wales* **139**, 85-106.

The brachiopod faunas are described from three successive stratigraphic units in the Bredbo area, between Canberra and Cooma - the Cappanana Formation, Colinton Volcanics and lower Rothlyn Formation. The first two have type localities in the area. There are 16 species in all, most of which occur at least in the Cappanana Formation, but there are no implications of a useful biostratigraphic succession. Many species are common to the Delegate River Mudstone south of Cooma and the Canberra Formation in Canberra, and the only previously unknown species is a probable *Rhynchotrema*, represented by just a few specimens. Comparison with faunas of known age in the Canberra-Yass area indicate a Wenlock (Early Silurian) age, most likely Sheinwoodian. This supports the most recently proposed stratigraphic framework, and the likelihood that the volcanic units in the region were probably erupted over relatively brief intervals of time.

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KEYWORDS: Brachiopods, Bredbo, Cappanana Formation, Colinton Volcanics, Rothlyn Formation, Silurian, Wenlock.

INTRODUCTION

Bredbo village is about 60 km south of Canberra on the Monaro Highway, on the eastern side of the Murrumbidgee River valley (Fig. 1). While the existence of Silurian rocks had been known for some time, the first detailed study of the area was by Browne (1944), with subsequent work for the 2nd edition of the Canberra 1:250 000 geological sheet (Best et al. 1964). More detailed mapping was carried out for the Michelago 1:100 000 sheet (Richardson 1979), later revised by Henderson (1990). Henderson's work is the basis of the geological map in Fig. 1, and the following account. Pickett (1982:60-62) listed the fossils that had been reported (but not described) from the Silurian units. The present paper documents the brachiopod fauna from the Bredbo area, complementing the description by Strusz (2013) of very poorly preserved brachiopods from a southern continuation of one of the units, the Cappanana Formation, east of Cooma.

GEOLOGICAL SETTING

The Bredbo area lies on a narrow graben-like meridional extension of the Silurian Canberra-Yass Shelf between Canberra and Cooma. The Silurian rocks are in faulted contact with the Murrumbidgee Batholith to the west, and are faulted against or unconformably overlies Llandoveryian graptolitic shale and Upper Ordovician sandstone and black shale to the east. Volcanic rocks of rhyolitic to dacitic composition dominate the succession, which comprises three conformable stratigraphic units: Cappanana Formation, Colinton Volcanics (both first used by Best et al. 1964) and Rothlyn Formation (introduced by Henderson 1990). The boundaries between these units are gradational, and not everywhere easily recognisable. Henderson thought the succession to be more akin to that in the Captains Flat basin to the east of Canberra, than to the rather more complex succession around Canberra itself. The type locality for the Cappanana Formation is along Cappanana Creek east of Bredbo, and for the

SILURIAN BRACHIOPODS FROM BREDBO AREA, NSW

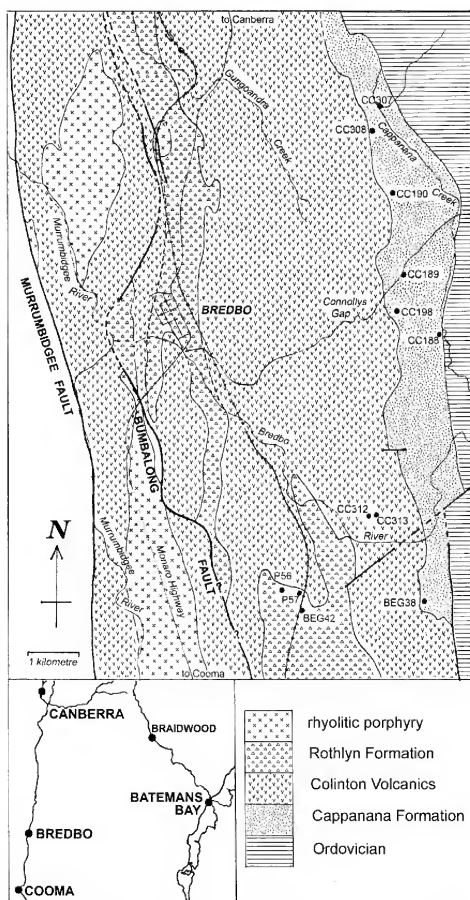


Figure 1. Geological map of the Bredbo area, simplified from Henderson (1990), showing localities referred to in this paper, and detailed in the Appendix. The rocks west of the Murrumbidgee Fault belong to the Murrumbidgee Batholith. Localities P56, P57 are those of Pillans (1974).

Colinton Volcanics is Colinton Hill, just north of the area shown in Figure 1.

Cappanana Formation

The unit immediately above the unconformity is the shallow-marine Cappanana Formation, comprising a discontinuous basal quartz-rich sandstone grading upward into shale and siltstone, some calcareous, with scattered thinly bedded and massive limestone lenses. Towards the top there are layers of dacitic tuff, mostly reworked. Thickness is 700 m or less. Macrofossils are common; those in the terrigenous beds appear to be mostly preserved as storm or slump

deposits, and include shells and trilobites that are generally dissociated and often broken. Fossils in the finer-grained rocks are generally distorted, probably as a result of both burial compaction and subsequent tectonic compression.

Colinton Volcanics

Partly marine but mainly subaerial, this thick volcanic unit overlies the Cappanana Formation. The base is defined as the first major volcanic layer. The formation is mostly dacitic crystal tuff, with rhyolites in the upper part; there are sporadic flows. There are also interbedded siltstones, and occasional limestone lenses. The formation is thickest in the north (up to 4000 m), thinning southward with increasing sedimentary content until disappearing near Cooma. This suggests that the volcanic centre was in the north or northeast. The sedimentary rocks contain shelly fossils, indicating a marine environment.

Rothlyn Formation

The Rothlyn Formation extends from near Bredbo to south of Cooma, and has also been found in a small area west of Michelago. It overlies the Colinton Volcanics, the base being defined as the first thick shale or limestone above the Volcanics, and differs from that formation in the composition of its volcanic content, and the much greater proportion of sedimentary rocks (about 50%). Shales dominate the latter, but there are also some thick limestone lenses, and sporadic sandstone beds especially towards the top of the unit; fossils indicate a marine environment. Apart from minor basalt, the volcanic rocks are rhyolitic to mostly dacitic, and always porphyritic. Henderson (1990) considered the volcanic centre to lie east to northeast of Cooma.

CORRELATION AND AGE

Henderson's detailed mapping extended from the southern edge of the Canberra area to Cooma (Henderson 1990). He showed that near Tharwa at the southern edge of Canberra, the Williamsdale Dacite Member near the top of the Colinton Volcanics was petrographically and geochemically very similar to the Deakin and overlying Laidlaw Volcanics, differing in much higher content of titanium, magnesium and total iron oxides. The uppermost levels of the Colinton Volcanics a little to the south (south from Williamsdale) are rhyolitic to dacitic crystal tuffs very similar to dacitic crystal tuffs at the base of the Laidlaw Volcanics. In particular, these crystal tuffs both contain allanite. Henderson considered it

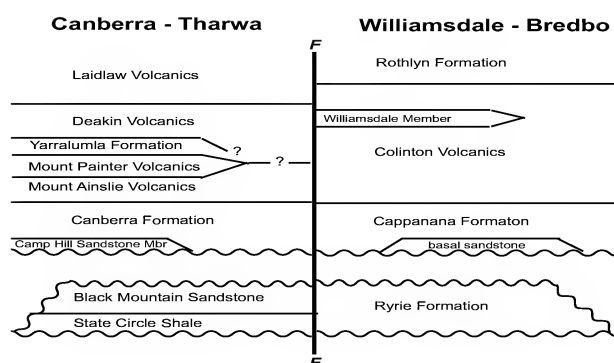


Figure 2. Correlation of Llandovery and Wenlock formations in the southern Canberra and Bredbo areas, based on Henderson (1990), Percival and Zhen (2017) and Strusz and Percival (in press).

	Cap	Col	Roth
<i>Eopholidostrophia</i> (<i>Megapholidostrophia</i>) sp.	■		
<i>Salopina mediocostata</i>	■		
<i>Atrypoidea</i> (<i>Atrypoidea</i>) <i>australis</i>	■		
<i>Navispira</i> cf. <i>bicarinata</i>	■		
? <i>Nucleospira paula</i>	■		
<i>Nanattegia</i> ? sp.	■		
<i>Hedeina oepiki</i>	■		
<i>Janius bowningensis</i>	■	■	
cf. <i>Clorinda</i> sp.	■		
<i>Mesoleptostrophia</i> (<i>Mesoleptostrophia</i>) <i>oepiki</i>	■	?	■
<i>Morinorhynchus</i> cf. <i>oepiki</i>	■	?	■
<i>Atrypa</i> ? sp.	■	■	■
<i>Spirinella caecistriata</i>	■	■	■
<i>Epelidoaegiria minuta chilidifera</i>		■	
<i>Rhynchotrema</i> ? sp.		■	
<i>Rufispirifer nucula</i> ?		■	

Figure 3. Species range chart. Abbreviations: Cap - Cappanana Formation; Col - Colinton Volcanics; Roth - Rothlyn Formation (lower part).

probable that the uppermost Colinton Volcanics were coeval with the lower Laidlaw Volcanics. It follows from this that the shales overlying this level in the Laidlaw Volcanics are readily correlatable with the onset of sedimentation in the Rothlyn Formation, overlying the Colinton Volcanics.

The Cappanana Formation north of Bredbo is unconformable on the Ryrie Formation, consisting of a basal siltstone overlain by sandstone and minor interbedded siltstone. The siltstone has yielded a sparse graptolite fauna of late Llandovery age (Richardson

and Sherwin 1975). This can be correlated with the State Circle Shale in Canberra, also with late Llandovery graptolites (Strusz and Jenkins 1982) and overlain by sandstone (the Black Mountain Sandstone). These are unconformably overlain by the Camp Hill Sandstone Member at the base of the Canberra Formation (Henderson 1981). There is similarly a discontinuous sandstone layer at the base of the Cappanana Formation. It is therefore reasonable, as shown by Henderson (1990) on his map, to correlate the Cappanana Formation with the Canberra Formation. All these relationships are summarised in Figure 2.

The distribution of species recognised in this paper is shown in Figure 3. Given the few localities in the Colinton Volcanics and Rothlyn Formation which have contributed to this study, it is likely that more of the taxa recorded in the Cappanana Formation extend to higher levels than shown. This also follows from the known distribution of species in the Canberra and Yass successions (Strusz 2010b), whose stratigraphic relationships and age have been discussed in detail by Percival and Zhen (2017) and Strusz and Percival (in press). Most of the species in the Bredbo fauna are known from those successions, where they extend from the mid-Wenlock into the Ludlow. Only three are there restricted to the Wenlock. *Mesoleptostrophia* (*Mesoleptostrophia*) *oepiki*, which is the most abundant species around Bredbo, is from the Canberra Formation, of Sheinwoodian age. *Hedeina oepiki* occurs in the Canberra Formation and in the Walker Volcanics, also of Sheinwoodian age. *Rufispirifer nucula* occurs in the Homerian Yarralumla Formation (but also in the Ludlow Molong Limestone farther north). It is clear that the succession from Cappanana Formation to at least the lower part of the Rothlyn Formation is of Wenlock age, and most probably Sheinwoodian.

SILURIAN BRACHIOPODS FROM BREDBO AREA, NSW

SYSTEMATIC PALAEOLOGY

The specimens documented in this study are held by Geoscience Australia in the Commonwealth Palaeontological Collection (catalogue numbers prefixed CPC) and the Research School of Earth Sciences, Australian National University (catalogue numbers prefixed ANU), both in Canberra. Geoscience Australia also holds unregistered material from localities in the Bredbo area with field numbers CC105-108, 188-198, 304-318, BEG27, 34-42. Details of the localities used in this study are given in the Appendix. Specimens cited from the fossil collection of the Australian Museum, Sydney, bear the prefix AMF.

There are no new species in this fauna, so the following descriptions highlight only those features needed to establish specific identification. Classification follows that in the Treatise on Invertebrate Paleontology, part H, Brachiopoda (Revised) (Kaesler 1997-2006), and references to taxa at and above the level of genus may be found in the relevant parts of the Treatise.

Nearly all the samples are heavily weathered and decalcified moulds, and most are distorted to a highly variable extent by burial compaction and subsequent tectonic compression. A consequence of the weathering is that very few of the specimens are capable of withstanding the making of latex casts, even after strengthening, so this has not been attempted.

Class STROPHOMENATA Williams et al., 1996
Order STROPHOMENIDA Öpik, 1934
Superfamily STROPHOMENOIDEA King, 1846
Family LEPTOSTROPHIIDAE Caster, 1939
Genus MESOLEPTOSTROPHIA Harper and Boucot, 1978
Subgenus MESOLEPTOSTROPHIA Harper and Boucot, 1978

Type species

Mesoleptostrophia kartalensis Harper and Boucot, 1978, *nom. nov. pro Stropheodonta (Leptostrophia) explanata* Paeckelmann and Sieverts, 1932, *non* Sowerby, 1842. Emsian, Turkey.

Mesoleptostrophia (Mesoleptostrophia) oepiki
(Strusz, 1985)
Fig. 4.

Synonymy

Leptostrophia (Leptostrophiella) oepiki Strusz, 1985: 110-111, figs 4-5.

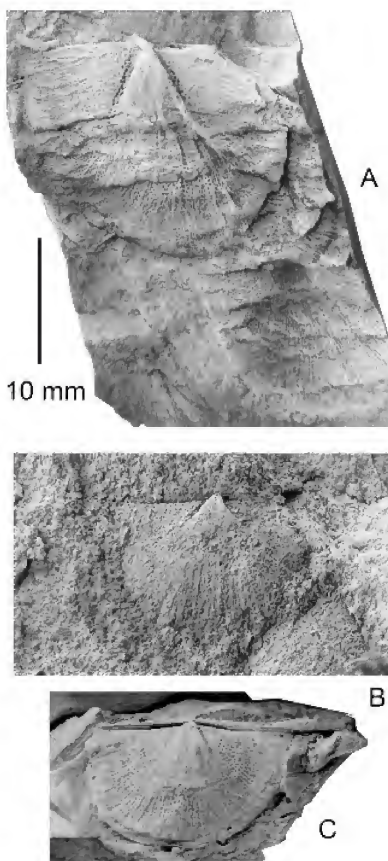


Figure 4. *Mesoleptostrophia (Mesoleptostrophia) oepiki*. A, CPC43761, ventral valve internal and external moulds, Cappingana Formation locality CC189; B, ANU33479B, ventral valve internal mould, Rothlyn Formation locality P57; C, holotype CPC24751, ventral valve internal mould, Canberra Formation, Fyshwick, Canberra.

M. (Mesoleptostrophia) oepiki (Strusz); Strusz 2010b, figs 2, 3K-M; Strusz 2011: 33-35, fig. 2.

Holotype

CPC24751; Canberra Formation, Wenlock, Fyshwick, A.C.T.

Material

CPC43761, 43762, 43835 to 43838, locality CC189; CPC43794, locality CC190; CPC43824, 43825, locality BEG42, ANU33479B, 33480 to 33482, Pillans locality 57. All ventral valves.

Diagnosis

‘Moderately concavo-convex *Mesoleptostrophia* of medium to large size, uniformly costellate, with long narrow alae, denticulation to 1/3 width of corpus; low ridges posterolaterally bounding subtriangular, posteriorly strongly impressed ventral muscle field, lateral to which valve floor is coarsely tuberculate; fine ventral myophragm; prominent notothyrial platform continuous with dorsal myophragm and pair of often prominent curved muscle-bounding ridges.’ (Strusz 2011:33).

Description

Material comprises only ventral valves, mostly incomplete internal moulds. Valve semioval, weakly to moderately convex with very small beak. Ornament evenly costellate, about 20 in an arc of 5 mm at 5 mm radius. Where preserved, alae narrow and long, mostly separated from corpus by broad, shallow reentrants. Greatest observed hinge width calculated at 32.7 mm, greatest observed width of corpus in front of reentrants over 22 mm; Wh/Wc about 1.5; Lv/Wc 0.8-0.9. Interarea low, flat to slightly concave, moderately to strongly apsacline; delthyrium open, triangular.

Cardinal margin denticulate for about 40% of corpus width. Muscle field triangular to flabellate, smooth-floored, with fine to weak myophragm, impressed especially posteriorly, bounded laterally by weak to low, coarsely tuberculate ridges; valve floor outside muscle field finely and densely tuberculate. Apical process small, low.

Remarks

The differences between the two known species of *Mesoleptostrophia* in the Silurian of the Canberra-Yass Shelf are fully discussed in Strusz (2003:10; 2011:33), Strusz (2013:7) and Strusz and Percival (in press). The only consistent distinction between these very close and quite variable species lies in external morphology: *M. (M.) oepiki* differs from *M. (M.) quadrata* (Mitchell, 1923) in developing long slender alae separated from the corpus by shallow to absent reentrants, and coarser ornament. It remains uncertain whether these differences are purely a reflection of differing environments, or phylogenetic change within a lineage, but the conclusion of Strusz and Percival was that the former is unlikely. Also very similar is *Mesopholidostrophia bendinensis* (Mitchell, 1923), but this can be distinguished by its very weak external ornament and detailed internal differences (Strusz 2013). The Bredbo occurrence can add nothing further.

Family EOPHOLIDOSTROPHIIDAE Rong and Cocks, 1994

Genus EOPHOLIDOSTROPHIA Harper, Johnson and Boucot, 1967

Subgenus MEGAPHOLIDOSTROPHIA Rong, Huang, Zhan and Harper, 2013

Type species

Eopholidostrophia (Megapholidostrophia) magnifica Rong et al., 2013:39-42, basal Anji Formation, Dakengwu, Chun'an County, Zhejiang Province, southeastern China; lower Rhuddanian, lower Llandovery, basal Silurian.

Diagnosis

‘Large, up to 32.5 mm wide, *Eopholidostrophia* subgenus with extravagant dorsal geniculation and long trail at angles of 70-100 degrees to disc; anterior margin trilobate.’ (Rong et al. 2013:39).

Eopholidostrophia (Megapholidostrophia) sp.
Fig. 5

Material

CPC43799. 43800, locality CC307.

Description

The ventral valves are all large (Lv to 41 mm, Ws to a calculated 58 mm) and strongly convex, with variable strength of geniculation. Alae small, may be separated from the corpus by a slot-like reentrant. Denticular plates triangular, extend to about 1/3 corpus width. Muscle field wide, flabellate, about 2/5 of valve length, posteriorly impressed, with a weakly grooved floor, divided by a fine myophragm. Valve floor outside muscle field finely but densely tuberculate.

The single dorsal internal mould is very incomplete and fairly strongly distorted; it is nearly flat, with narrow alae. Cardinal process lobes upright, disjunct, separated from a notothyrial platform by a prominent depression. Extending forward from the platform is a long fairly robust myophragm, and a pair of shorter moderately divergent ridges flanking a weakly expressed muscle field. Socket plates well developed, widely divergent.

Remarks

The relationship of *Eopholidostrophia (Megapholidostrophia)* to *E. (Eopholidostrophia)* is fully discussed by Strusz and Percival (in press). The material from Bredbo is sparse - one dorsal internal mould, six ventral internal moulds, all incomplete

SILURIAN BRACHIOPODS FROM BREDBO AREA, NSW

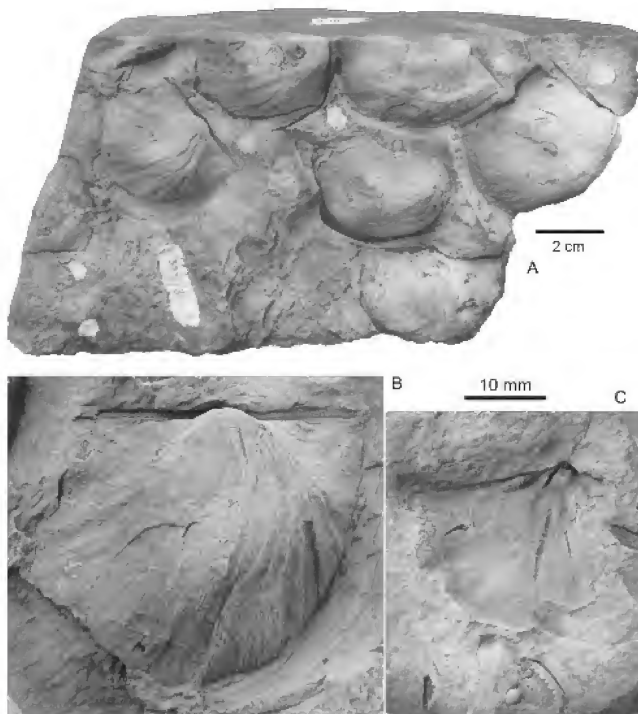


Figure 5. *Eopholidostrophia* (*Megapholidostrophia*) sp. A, CPC43800, slab with six distorted ventral valve internal moulds; B, nearly complete ventral valve internal mould on CPC43800; C, CPC43799, incomplete and strongly distorted dorsal valve internal mould; locality CC307, Cappauna Formation.

and not as well preserved as what is almost certainly the same species from farther south in the Quidong area, so can add nothing to that discussion.

Superfamily PLECTAMBONITOIDEA Jones, 1928
Family XENAMBONITIDAE Cooper, 1956
Subfamily AEGIROMENINAE Havlíček, 1961
Genus EPILIDOAEGIRIA Strusz, 1982

Type species

Aegiria (*Epelidoaegiria*) *chilidifera* Strusz, 1982.
Walker Volcanics, Canberra, Australia; Wenlock, Lower Silurian.

Epelidoaegiria minuta chilidifera Strusz, 1982
Fig. 6

Synonymy

Aegiria (*Epelidoaegiria*) *chilidifera* Strusz, 1982: 116-118, figs 9, 10.

Epelidoaegiria minuta chilidifera Strusz, 1982; Strusz 2003: 17-19, figs 12, 13, *cum syn.*

Holotype

CPC20387; Walker Volcanics, Sheinwoodian, Canberra, ACT.

Material

CPC43805 to 43810, locality CC312.

Diagnosis

'Relatively large and rarely sulcate *Epelidoaegiria* with fine unequally parvicostellate ribs, more costae on dorsal valve than on ventral, hinge line usually less than greatest width, prominent crescentic pseudodeltidium, and dorsal median septum extending slightly beyond bema to about valve mid-length' (Strusz 2003:17).

Remarks

As summarised by Strusz and Percival (in press), the two subspecies of *E. minuta* are very close morphologically, but can be separated on a number of points (see Table 5 in Strusz 2003). The generally distorted and rather poorly preserved Bredbo specimens are about the same maximum size as *E. minuta minuta* from Yass (measured Ls up to 4.2 mm, Ws up to 6.7 mm), but ribbing is finer and less angular than in that subspecies, there is no dorsal sulcus, the bema is weak or absent, and where present is the same length as the dorsal myophragm, both being less than the length of the valve. From these it follows that the Bredbo specimens belong to the type Canberra subspecies *E. m. chilidifera*.

Class RHYNCHONELLATA Williams et al., 1996
Order ORTHOTETIDA Waagen, 1884
Suborder ORTHOTETIDINA Waagen, 1884
Superfamily CHILIDIOPSOIDEA Boucot, 1959
Family CHILIDIOPSIDAE Boucot, 1959
Subfamily CHILIDIOPSINAE Boucot, 1959
Genus MORINORHYNCHUS Havlíček, 1965

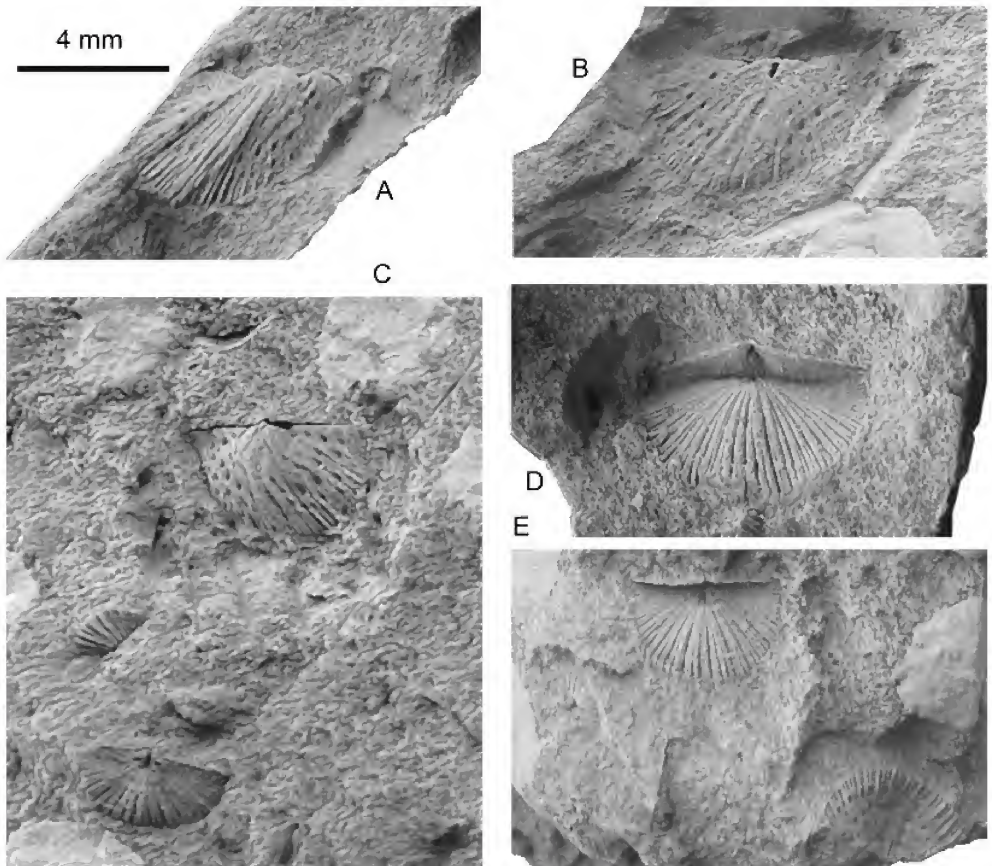


Figure 6. *Epelidoaegiria minuta chilidifera*. A, CPC43808, strongly distorted ventral valve internal mould; B, CPC43806, strongly distorted dorsal valve internal mould with weak myophragm, and bema just visible on right side; C, CPC43810, part of slab with ventral valve internal mould and dorsal valve external mould; D, CPC43807, dorsal valve and ventral valve external mould; E, CPC43809, dorsal valve external mould; locality CC312, Colinton Volcanics.

Type species

Morinorhynchus dalmanelliformis Havlíček, 1965, p. 291; Ludlow, Prague Basin, Bohemia.

Morinorhynchus sp. cf. *M. oepiki* Strusz, 1982
Fig. 7

Synonymy

cf. *Morinorhynchus oepiki* Strusz, 1982:119-122, figs 14-15.

Holotype

CPC20987; Walker Volcanics, Wenlock, Canberra, ACT.

Material

CPC43770, 43777, 43830, 43831, locality CC189; CPC43801, locality CC307; CPC43821, locality BEG38; ANU33483-33484 (counterparts), 33488, Pillans locality 56.

Description

Shell medium-sized, subquadrate in outline; ventral valves gently convex with greatest curvature at umbo, dorsal valve almost flat, anterior commissure rectimarginate. Largest observed ventral valve 17 mm long and about 21 mm wide (Ls/Ws ca 0.8), hinge almost as wide as valve, greatest width towards mid-

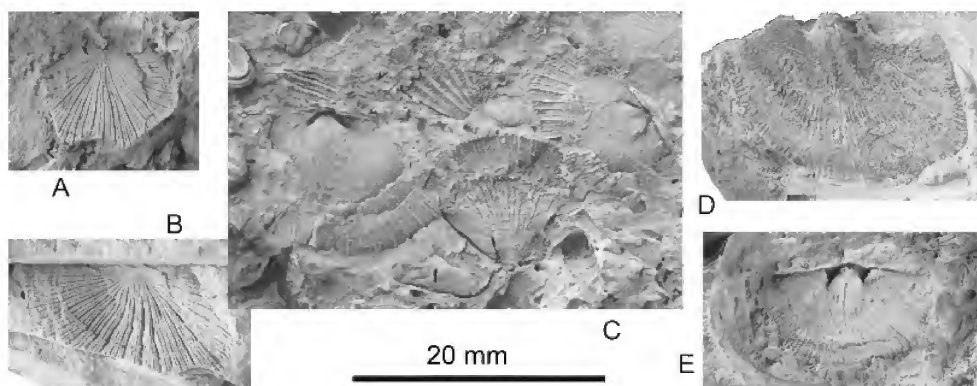


Figure 7. *Morinorhynchus cf. oepiki*. A, CPC43769, incomplete dorsal valve external mould; B, CPC43830, incomplete ventral valve external mould; C, CPC43777, dorsal and ventral valve internal moulds; D, CPC43770, ventral valve internal mould; E, CPC43831, ventral valve internal mould; locality CC189, Cappanana Formation.

length. Ventral interarea strongly apsacline, delthyrial structure not preserved; dorsal interarea not known. Ornament finely unequally parvicostellate, about 28 ribs in 5 mm at 5 mm from beak; growth lines fine, crowded, well developed in intercostal furrows.

Teeth triangular, supported by strong, straight, upright dental plates diverging at about 70–80°. Muscle field flabellate, with faint myophragm, other details not preserved.

Dorsal interior known from one adult fragment, one juvenile. In juvenile, muscle field subquadrate, divided by broad low myophragm; socket plates very gently curved, diverge at 90°, continuous with low ridges flanking muscle field; cardinal process not preserved. Adult fragment shows one small, slightly curved socket plate, broad very low myophragm.

Remarks

The available material is sparse, somewhat distorted, and mostly fragmentary and poorly preserved; it is likely that better material would permit positive identification as *M. oepiki*. Allowing for distortion, ventral interior CPC43770 (Fig. 7D) is comparable with CPC24784, from the Canberra Formation in Fyshwick, Canberra (Strusz 1985:fig. 7F), which has dental plates less strongly curved than the type specimens from the Walker Volcanics of western Canberra. The dorsal interior CPC43777 is very like paratype CPC20419, from the Walker Volcanics (Strusz 1982:fig. 15D) except for less curvature of the socket plates. The species is also known from the Cappanana Formation east of Cooma (Strusz, 2013:8–9), where it dominates the fauna. A new species from the Delegate River Mudstone of

Quidong (Strusz and Percival, in press) differs in a more elongate outline, with a subelliptical rather than subquadrate outline, a less strongly apsacline ventral interarea, and more strongly divergent socket plates.

Suborder ORTHIDINA Schuchert and Cooper, 1932
Superfamily ENTELETOIDEA Waagen, 1884
Family DRABOVIIDAE Havlíček, 1950
Subfamily DRABOVIINAE Havlíček, 1950
Genus SALOPINA Boucot in Boucot et al., 1960

Type species

Orthis lunata J. de C. Sowerby, 1839; Ludlow, Shropshire.

Salopina mediocostata Strusz, 1982

Fig. 8

Synonymy

Salopina mediocostata Strusz, 1982; Strusz, 2011:36, fig. 4; *cum syn.*

Holotype

CPC20337; Walker Volcanics, Wenlock, Canberra, ACT.

Material

CPC43763 to 43766, 43768, 43774, locality CC189.

Diagnosis

‘Small subequally biconvex, broadly sulcate *Salopina* with single median costa on dorsal valve;

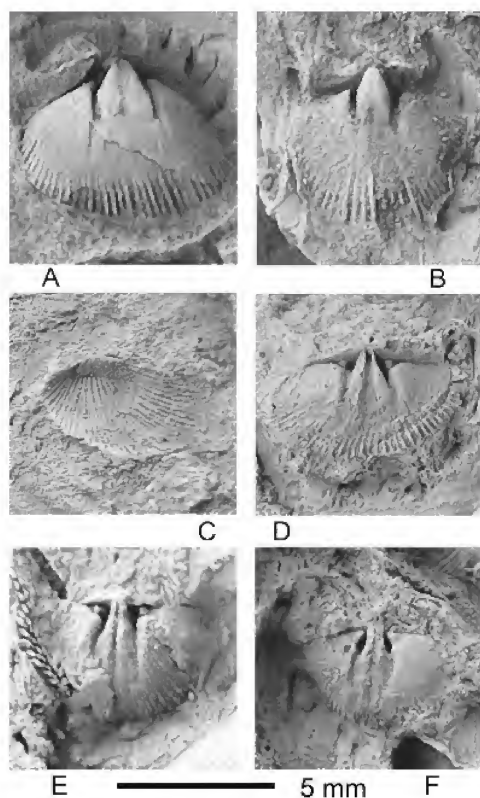


Figure 8. *Salopina mediocostata*. A, CPC43763, ventral valve internal mould with relatively wide muscle field; B, CPC43766, ventral valve internal mould with narrow muscle field; C, D, CPC43765, dorsal valve external and internal moulds; E, CPC43774, dorsal valve internal mould; D, CPC43768, dorsal valve internal mould; locality CC189, Cappanana Formation.

teeth prominent, triangular, on short robust dental plates; ventral muscle field confined to subtriangular delthyrial cavity, somewhat raised, with abrupt fall at anterior edge; dorsal muscle field subquadrate with strongly raised lateral margins; widely separated subtriangular posterior adductor scars smaller and less impressed than anterior scars and separated from notothyrial cavity by oblique ridges; dorsal myophragm prominent, may extend beyond muscle field.' (Strusz 2002:68-69).

Remarks

Only separated valves have been seen in the Bredbo collections, and as with other species in the

fauna most are not well preserved. Nevertheless the better ones are in complete accord with previous records of the species both externally and internally. The largest ventral valve, CPC43763, is 5.2 mm long, 6.9 mm wide, with Ls/Ws 0.75, Wh/Ws ca 0.8. This compares with values for the type series from the Walker Volcanics: maximum length 4.7 mm and width 5.9 mm, mean Lv/Ws 0.80, Wh/Ws 0.83. For the species of *Salopina* in the Yass succession, Strusz (2002:69) considered the form of the muscle fields, particularly that of the dorsal valve, to be the most reliable distinguishing feature. As at Yass, the Bredbo specimens have the species-specific longer, more quadrate dorsal field with distinctively shaped muscle bounding ridges and adductor scars, together with a myophragm which extends beyond the anterior edge of the field.

Order PENTAMERIDA Schuchert and Cooper, 1931
Superfamily CLORINDOIDEA Rzhonsnitskaya, 1956

Family CLORINDIDAE Rzhonsnitskaya, 1956
Genus CLORINDA Barrande, 1879

Type species

Clorinda armata Barrande, 1879. Hlubočepy Limestone, Prague Basin, Bohemia; Devonian.

Clorinda? sp. indet.
Fig. 9

Material

CPC 43826, locality BEG42; CPC43832, locality CC189.

Remarks

The two specimens are very small internal moulds - the largest is CPC43826, with a width of 3.75 mm - and are poorly preserved. There is no sign of crura, and by comparison with *Clorinda minor* (Booker, 1926) from the Yass Syncline, as revised by Strusz (2005), both are probably ventral valves. Both have median septa extending to about 2/5 valve length, which appear to support short, narrow spondylia. In the absence of larger specimens and usable dorsal valves, even generic identification is uncertain.

Order RHYNCHONELLIDA Kuhn, 1949
Superfamily RHYNCHOTREMATOIDEA
Schuchert, 1913
Family RHYNCHOTREMATIDAE Schuchert, 1913
Subfamily RHYNCHOTREMATINAE Schuchert, 1913

SILURIAN BRACHIOPODS FROM BREDBO AREA, NSW

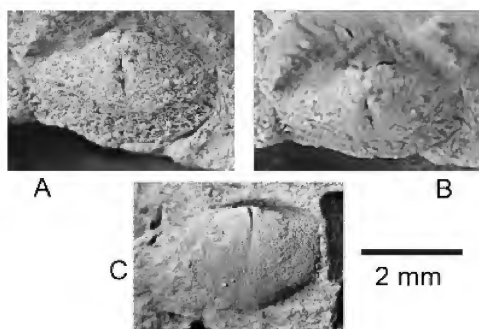


Figure 9. *Clorinda?* sp. indet. A, B, CPC43826, probable ventral internal mould with median septum supporting small apical spondylium, just visible in oblique posterior view (B); locality BEG42, Rothlyn Formation; C, CPC43832, slightly better specimen with median septum, narrow spondylium, smooth exterior; locality CC189, Cappanana Formation.

Genus RHYNCHOTREMA Hall, 1860

Type species

Atrypa increbescens Hall, 1860. Caradoc, Canada.

Rhynchotrema? sp. indet

Fig. 10

Material

CPC 43816-43820, locality CC315. The available material comprises jumbled and mostly fragmentary external and internal moulds, of which eight, while not well preserved, are of use: one almost complete ventral external mould, two incomplete ventral internal moulds, two incomplete dorsal internal moulds, two moulds of the posterior end of a shell (one internal), and one of the anterior end.

Description

Shell small (greatest observed Ws 12.7 mm, Ls ca 11.8 mm, Ls/Ws ca 0.93), biconvex, subpentagonal, with prominent suberect ventral beak. Fold and

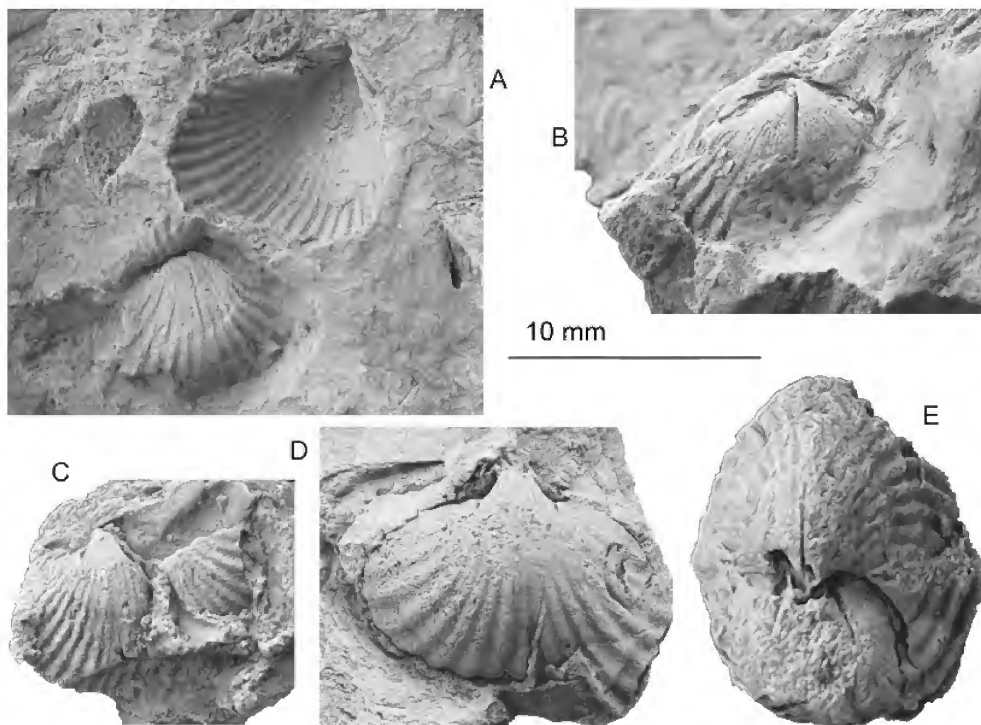


Figure 10. *Rhynchotrema?* sp. A, CPC43816, ventral valve external mould and dorsal valve internal mould; B, CPC43817, incomplete dorsal valve internal mould; C, CPC43820, ventral valve internal mould; D, CPC43818, ventral valve internal mould; E, CPC43819, posterior view, internal mould of conjoined dorsal and ventral valves; locality CC313, Colinton Volcanics.

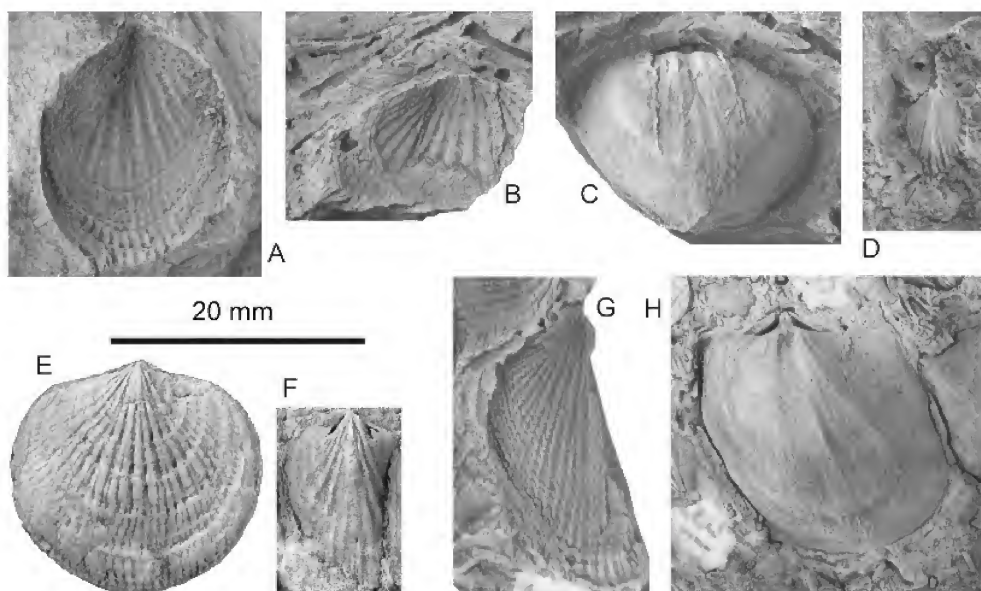


Figure 11. A-D, *Atrypa?* sp. A, CPC43780, ventral valve external mould; B, C, CPC43778, incomplete dorsal valve external mould and counterpart internal mould; D, CPC43779, juvenile ventral valve internal mould; all from locality CC189, Cappingana Formation. For comparison: E-F, *Atrypa (Atrypa) cf. dzwinogrodensis*; E, AMF29279, dorsal valve, Yarralumla Formation, Canberra, F, AMF129699, juvenile ventral valve internal mould, probably basal Black Bog Shale, Yass. G-H, *Atrypa (Atrypa) duntroonensis*; G, AMF110348, incomplete ventral valve external mould; H, AMF110407, dorsal valve internal mould; both Canberra Formation, Canberra.

sulcus faint or absent posteriorly, broad and very low anteriorly. Plications simple, extend from beaks. Cardinal area low, delthyrium wide, low, partly closed laterally by deltidial plates; foramen probably mesothyrid. Cardinal margin about 1/3 shell width.

Dental plates thin, widely separated, divergent forward and slightly laterally, flat to gently concave medially, clearly separated from valve walls; teeth small. Muscle field uncertain: in one poorly preserved posterior internal mould it appears to be elongate and somewhat impressed, in the other it has been damaged but appears to be shorter.

Cruralium short, supported by narrow, low to fairly well developed median septum; other details obscure or damaged.

Remarks

Identification of these specimens to even family level is uncertain. With well developed dental plates not fused to the valve walls, they cannot be Orthorhynchulids or Leptocoeliids. Ribs extending from the beaks means they are unlikely to be Trigonirhynchids. Of Silurian Rhynchotrematids, *Pleurocornu* Havlíček, 1961 differs markedly in

its triangular outline and few plications, while *Stegerhynchus* Foerste, 1909 and *Stegocornu* Dürkoop, 1970 differ in having much stronger pauciplicate folds extending from at or near the beak. The Bredbo form differs from more typical *Rhynchotrema* in its very weak fold and sulcus, and small teeth.

Order ATRYPIDA Rzhonsnitskaya, 1960
Suborder ATRYPIDINA Moore, 1952
Superfamily ATRYPIDEA Gill, 1871
Family ATRYPIDAE Gill, 1871
Subfamily ATRYPINAE Gill, 1871
Genus ATRYPDA Dalman, 1828

Type species

Anomia reticularis Linnaeus, 1758; Ludlow, Gotland.

Atrypa? sp
Fig. 11.

Material

CPC43778 to 43780, locality CC189;
CPC43815, locality CC313; CPC43827, locality BEG42.

Remarks

As discussed by Strusz (2011:43–44), the two described species of *Atrypa* from the Silurian of the Canberra–Yass Shelf are morphologically close, distinguished externally by differences in valve convexity. *Atrypa* (*A.*) *duntroonensis* Mitchell and Dun, 1920 is less markedly dorsibiconvex than *A.* (*A.*) sp. cf. *dzwinogrodensis* Kozłowski, 1929, with the ventral valve flanks often gently concave in the latter but not the former. Moreover, Strusz noted that these Australian taxa combine features of several genera within the subfamily, distinguished on internal as well as external morphology.

As only poor dorsal and no ventral interiors are known, even identification to generic level is uncertain, although on general appearance it is likely that one of the two above species of *Atrypa* occurs at Bredbo. The very strong, even convexity of dorsal valve CPC43778 (Fig. 11C), and the coarse proximal ribs on CPC43780 (Fig. 11A) are suggestive of *A.* (*A.*) sp. cf. *dzwinogrodensis* (compare AMF 29279, Fig. 11E), but of themselves these are far from conclusive.

Suborder LISSATRYPIDINA Copper, 1996
 Superfamily LISSATRYPOIDEA Twenhofel, 1914
 Family LISSATRYPIDAE Twenhofel, 1914
 Genus ATRYPOIDEA Mitchell and Dun, 1920
 Subgenus ATRYPOIDEA Mitchell and Dun, 1920

Type species

Meristina (?) *australis* Dun, 1904; Ludlow, New South Wales.

Atrypoidea (*Atrypoidea*) *australis* (Dun, 1904)
 Fig. 12

Synonymy

Meristina (?) *australis* Dun, 1904: 318–319, pl. LXI, figs 3a–e.

Atrypoidea australis; Mitchell and Dun, 1920: 272, pl. XIV, figs 1–18, pl. XV, figs 8–9, pl. XVI, figs 7, 13.

Atrypoidea (*Atrypoidea*) *australis* (Dun, 1904); Strusz 2007:24–33, figs 16–21, *cum syn.*

Lectotype

MMF4014 (Geological Survey of NSW, Londonderry NSW); Molong Limestone, Ludlow, Molong, NSW.

Material

CPC43781, locality CC189; CPC43795 to 43797, locality CC198; CPC43822, locality BEG38.

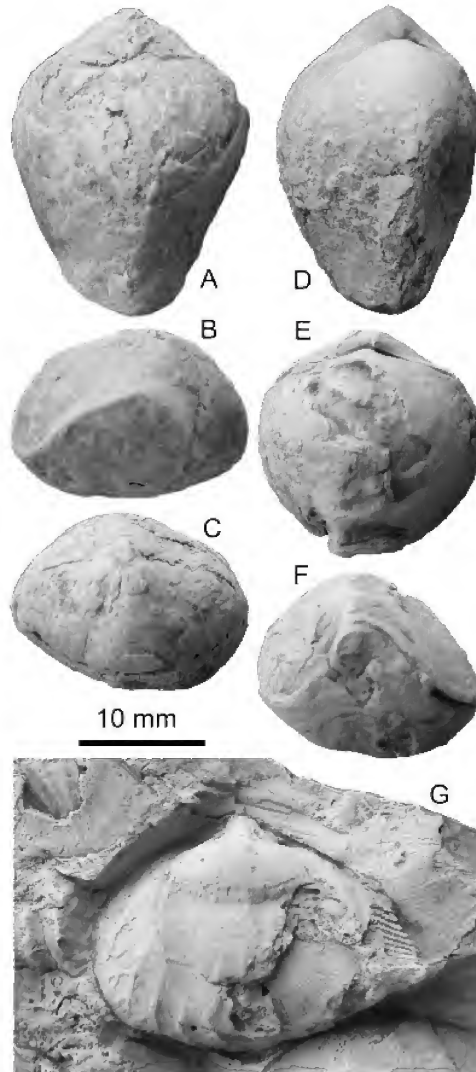


Figure 12. *Atrypoidea* (*Atrypoidea*) *australis*. A–C, CPC43795, shell in dorsal, anterior and posterior aspects; D, CPC43796, shell in dorsal aspect; E–F, CPC43798, shell in dorsal and anterior aspects; G, CPC43781, longitudinally compressed ventral valve internal mould. A–F from locality CC198, G from locality CC189, Capanana Formation.

Diagnosis

‘Large, biconvex, generally rotund *Atrypoidea*, mostly somewhat longer than wide, with weak fold and sulcus but usually large rounded dorsal deflection

of anterior commissure, moderately curved lateral commissure; large delthyrium with narrow deltidial plates in smaller shells, obscured in larger shells with low, incurved ventral beak adpressed to dorsal umbo; cardinal extremities rounded; teeth and conical sockets widely divergent.' (Strusz 2007a:327).

Description

The shells from locality CC198 are generally worn, only three being measurable; other localities yielded four usable ventral internal moulds. There are no dorsal internals, and preservation is generally poor. Outline variable, elongate oval or shield-shaped to subcircular, greatest width between 40% and 50% of length. Largest shell 24.5 mm long, 16.7 mm wide, 14.1 mm thick (Ls/Ws 1.25, Ts/Ls 0.57). Lateral profile dorsibiconvex; ventral beak small, adpressed to dorsal valve. Broad poorly delineated dorsal fold arises anterior to mid-length, becoming strong only near anterior margin. Delthyrium large, triangular.

Ventral internal details poorly preserved. Teeth small, widely divergent, separated from cardinal margin by narrow slits. Muscle field impressed, subtriangular. Dorsal internal structures not seen.

Remarks

Despite the limited material, identification of the Bredbo specimens is certain. The measured specimens plot within the envelope of the data plots in Strusz (2007a), as do those from the Cappanana Formation east of Cooma (Strusz 2013:10-11), and can be matched with the published specimens from Yass and Molong - e.g. CPC43796 (Fig. 12D) is very similar to CPC39038 (Strusz 2007a:fig. 17J) from the Yass Formation, while CPC43798 (Fig. 12E-F) resembles AMF29197, the lectotype of synonymous *Atrypoides angusta* Mitchell and Dun, 1920 from an unknown level at Yass (Strusz 2007a:fig. 16B), and AMF29193 from the Molong Limestone (Strusz, 2007a:fig. 19D).

Order ATHYRIDIDA Boucot, Johnson and Staton, 1964

Suborder ATHYRIDIDINA Boucot, Johnson and Staton, 1964

Superfamily NUCLEOSPIROIDEA Davidson, 1881

Family NUCLEOSPIRIDAE Davidson, 1881

Genus NUCLEOSPIRA Hall in Davidson, 1858

Type species

Spirifer ventricosus Hall, 1857. Lochkovian, New York.

?*Nucleospira paula* Strusz, 2007
Fig. 13

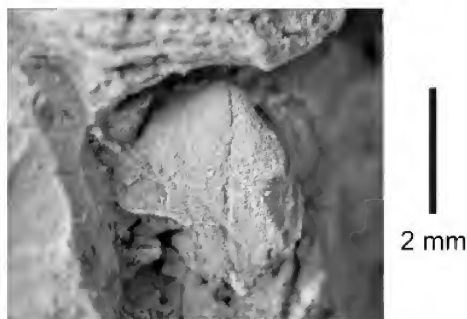


Figure 13. ?*Nucleospira paula*. CPC43767, dorsal? valve internal mould, partly concealed below a calical mould of a small tryplasmatic rugose coral; locality CC189, Cappanana Formation.

Synonymy

Nucleospira paula Strusz, 2007b:89-91, figs 2-4.

Holotype

ANU9573; Yarwood Siltstone Member, Black Bog Shale, Ludfordian, Yass NSW.

Material

CPC43767, locality CC189.

Remarks

The single specimen is a very small (estimated Ls 2.6 mm, Ws 2.9 mm) and incomplete internal mould of a smooth convex valve with a distinct myophragm extending the full length of the valve. While posterior details are poorly preserved, there is a suggestion of sockets parallel to the cardinal margin, indicating a dorsal valve, and comparable with the structure shown by the holotype (Strusz 2007b:fig. 2B).

Superfamily ANOLOTHECOIDEA Schuchert, 1894

Family ANOLOTHECIDAE Schuchert, 1894

Subfamily COELOSPIRINAE Hall and Clarke, 1895

Genus NAVISPIRA Amsden, 1983

Type species

Anoplothea (*Coelospira*) *saffordi* Foerste, 1903.

Navispira? sp. cf. *N?* *bicarinata* Strusz, 2007
Fig. 14.

SILURIAN BRACHIOPODS FROM BREDBO AREA, NSW

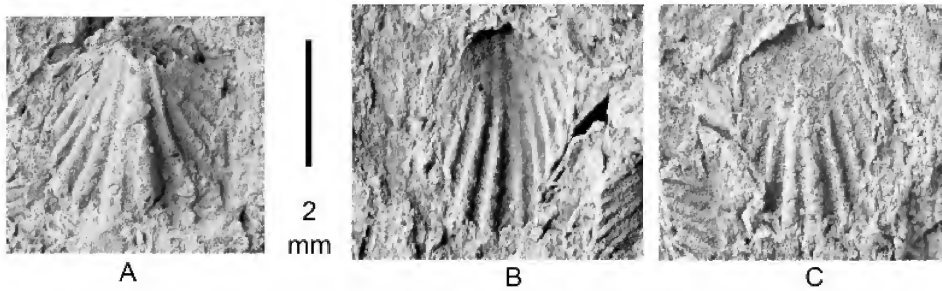


Figure 14. *Navispira?* cf. *bicarinata*. A, CPC43776, ventral valve internal mould; B-C, CPC43773, counterpart ventral and dorsal valve external moulds; locality CC189, Cappingana Formation.

Synonymy

cf. *Navispira?* *bicarinata* Strusz, 2007b:93-96, Figs 7-9.

Material

CPC43773, 43776, locality CC189.

Description

The two tiny specimens are a posteriorly damaged ventral internal mould, and counterpart ventral and dorsal external moulds, both distorted and rather poorly preserved. The former specimen is subcircular, 3.3 mm wide, and shows a very prominent rounded fold formed by two strong moderately divergent ribs. There are four pairs of lateral plications. While the umbonal region is damaged, there is the suggestion of short divergent dental plates. The second individual is similar, but with only three pairs of lateral plications on the ventral valve, and a very poorly preserved but apparently smooth umbonal area; Ws is 2.3 mm, Ls 3.5 mm. Microornament is not preserved.

Remarks

Strusz (2007b:97) has discussed the relationship between *Silurian Navispira* and *Coelospira*, concluding that the feature most characteristic of the former is the keel-like form of the ventral fold. Species of both genera occur at Yass, and the Bredbo specimens are very like *Navispira?* *bicarinata*, differing in slightly larger size, less divergent ribs on the fold with no sign of the fine median rib, and narrower lateral ribs (which could be an effect of distortion). While the Bredbo specimens are probably conspecific, they are too poor for confident identification.

Order SPIRIFERIDA Waagen, 1883
Superfamily CYRTIOIDEA Frederiks, 1924

Family CYRTIIDAE Frederiks, 1924

Subfamily EOSPIRIFERINAE Schuchert, 1929

Genus NANATTEGIA Strusz, 2010

Type species

Nanattegia yassensis Strusz, 2010a:93-97, figs. 6-7. Upper Silurian (Gorstian to Pridoli), Yass Syncline, NSW.

Diagnosis

'Tiny ventribiconvex spiriferide with V-shaped sulcus defined by strong plications, low dorsal fold defined by distinct furrows, subdued radially capillate micro-ornament; dental plates thin, subparallel, intrasinal to sulcus-bounding; cardinal process bilobed, outer hinge plates steeper than crural plates.' (Strusz, 2010a)

Nanattegia? sp.

Fig. 15.

Material

CPC43771, 43472, 43775, locality CC189.

Description

Material poorly preserved, very small, incomplete. Ventral valve pyramidal, capillate, capillae narrower than intervening flat-bottomed furrows; sulcus narrow, flanked by prominent plications. Dorsal valve gently convex, with low fold posteriorly narrow, flaring forward of mid-length, flanked by fairly shallow furrows. Outer plications, if present, very faint. Wide hinge line.

Ventral interior with thin upright dental plates, probably intrasinal to sulcus-bounding. Dorsal interior with small, steep outer hinge plates. No other details visible.

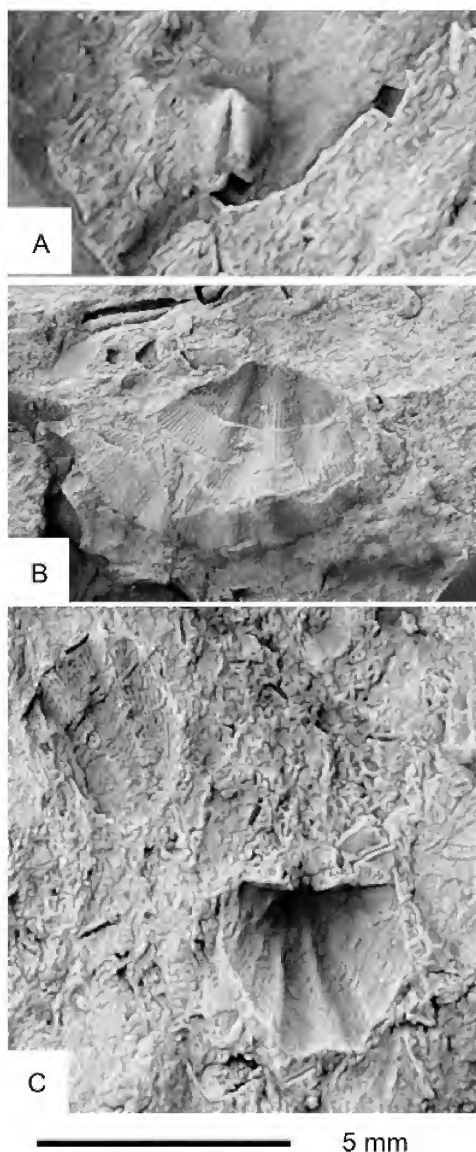


Figure 15. *Nanattegia?* sp. A, CPC43771, ventral valve; B, CPC43775, incomplete external mould showing *Myriospirifer*-type capillae; C, CPC43772, relatively large pyramidal ventral valve external mould, and nearby incomplete dorsal? valve external mould showing style of capillae; locality CC189. Capanana Formation.

Remarks

These tiny spiriferides show the general external character of the genus, but the interiors are too poorly

preserved for positive generic identification. They differ from other small spiriferides in the Bredbo fauna in their *Myriospirifer*-type micro-ornament (Havlíček 1980). The others have coarser capillae as wide as the intervening furrows, and are considered to be juvenile *Hedeina*.

Genus HEDEINA Boucot, 1957

Type species

Anomia crista Linnaeus, 1758. Silurian, Gotland.

Diagnosis

Eospiriferine with prominent smooth fold defined by strong U-shaped furrows; few lateral plications, the innermost narrower than fold but generally strong, the remainder decreasing rapidly in prominence laterally; dental plates extrasinal; ctenophoridium present.

Remarks

The above diagnosis is derived from the extensive discussion of the relationship between several eospiriferine genera in Strusz (2010a:97-101).

Hedeina oepiki Strusz, 2010
Fig. 16.

Synonymy

Hedeina oepiki Strusz, 2010a:103-104, fig. 13.

Holotype

CPC24871; Canberra Formation, Sheinwoodian, Canberra, ACT.

Material

CC43793, locality CC188; CPC43782 to 43790, locality CC189; CPC43839, locality CC307; CPC43823, locality BEG38.

Diagnosis

'Small *Hedeina* close to *H. bruntoni*, differing in subtriangular outline, wider hinge line, narrower fold.' (Strusz, 2010a:103)

Description

Shell fairly small, moderately ventribiconvex; outline transverse (Ls/Ws ca 0.8), subtriangular with prominent ventral umbo, wide hinge line (Wh/Ws 0.75-0.8), rounded cardinal angles; maximum width a little posterior to mid-length. Fold prominent, broadly rounded, flanked by less prominent pair of rounded plications originating at beak; 2-3 pairs

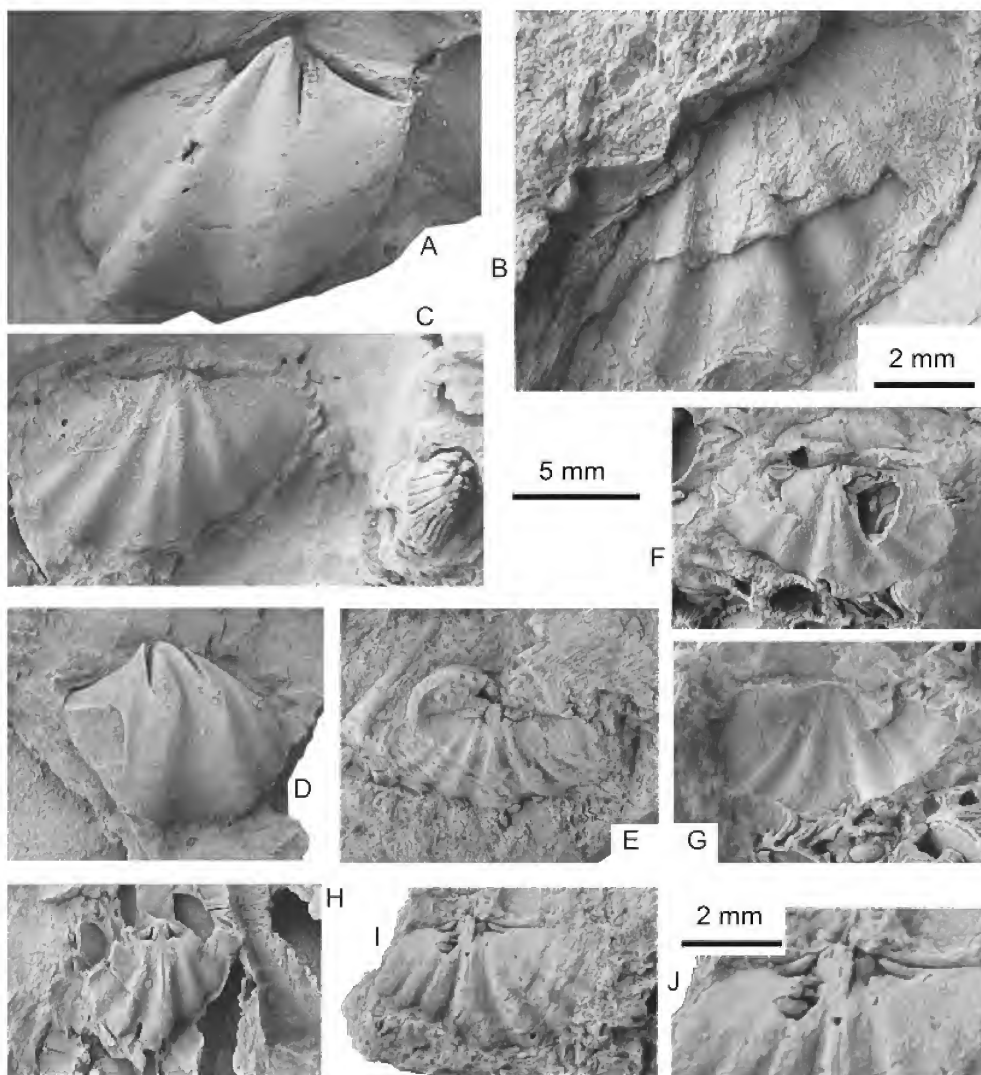


Figure 16. *Hedeina oepiki*. A, CPC43782, ventral valve internal mould; B, CPC43786, partly decorticated dorsal valve showing capillae; C, CPC43789, dorsal valve internal mould (and adjacent calical mould of syringaxonid? rugose coral); D, CPC43783, ventral valve internal mould; E, CPC43787, dorsal valve internal mould; F-G, CPC43785, counterpart dorsal valve internal and external moulds; H, CPC43784, incomplete dorsal valve internal mould; I-J, CPC43788, dorsal valve internal mould and enlarged view of the cardinalia, showing the small ctenophoridium; locality CC189, Capanana Formation.

lateral plications, low beside fold, weakening outwards from low to faint. Microornament finely capillate, crossed by low growth lamellae which become crowded marginally in larger shells and with poor preservation may appear fimbriate.

Ventral interarea concave with open delthyrium

flanked by narrow upright deltidial plates. Teeth small, dental plates robust, extrasinal, extending as far forward as 1/3 valve length. Muscle field obscure. Faint myophragm may be visible.

Cardinal process a small ctenophoridium. Sockets narrow, deeply conical, widely divergent; crural plates short but well developed, inclined; low

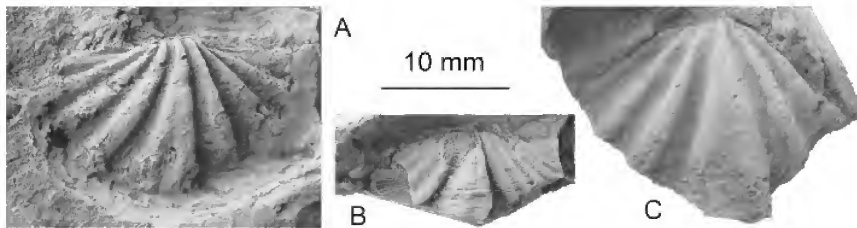


Figure 17. *Janius bowningensis*. dorsal valve internal moulds; A, CPC43771, B, CPC43791, C, CPC43772; A and C locality CC189, Cappauna Formation; B locality CC312, Colinton Volcanics.

notothyrial platform, weak myophragm.

Remarks

These generally rather poor specimens are placed in *H. oepiki* because of their small size, transverse shape, and relatively narrow fold. The species is otherwise known from the Canberra Formation and Walker Volcanics in the Canberra region, of Sheinwoodian age.

Genus JANIUS Havlíček, 1957

Type species

Spirifer nobilis Barrande, 1848; Wenlock, Bohemia.

Diagnosis

Strongly multiplicate eospiriferine with plications that bifurcate and intercalate, and may be present in sulcus (after Johnson and Hou 2006:1696).

Janius bowningensis (Mitchell, 1921)

Fig. 17

Synonymy

Spirifer bowningensis Mitchell, 1921:545-546, pl. 31 figs 21-22.

Janius bowningensis (Mitchell, 1921); Strusz, 2010a:90-93, figs 4-5, *cum syn.*

Lectotype

AMF29450, Black Bog Shale, Ludfordian, Yass NSW.

Material

CPC43791, 43792, locality CC189; CPC43811, locality CC312.

Diagnosis

'Fairly large, equibiconvex thin-shelled species of *Janius* with subdued ventral beak, wide U-shaped

ventral sulcus and medially depressed dorsal fold which is noticeably widened marginally; plications curved outwards, subdivision variable, often asymmetric, sometimes by marginal trifurcation' (Strusz 2010a:90).

Remarks

The Bredbo specimens are four poorly preserved dorsal internal moulds and one fragmentary external mould, but are in every available aspect identical with the better-preserved specimens from the Yass Syncline. The largest is 16 mm long, and shows the typical wide, anteriorly flared fold with a depressed axis. A second is 10 mm long, with width more than twice length. The single external shows strong capillae crossed by crowded nodose growth lines - as in CPC39998 from Yass (Strusz 2010a:fig. 4H).

Suborder DELTHYRIDINA Ivanova, 1972

Superfamily DELTHYRIDOIDEA Phillips, 1841

Family DELTHYRIDIDAE Phillips, 1841

Subfamily HOWELLELLINAE Johnson and Hou, 1994

Genus RUFISPIRIFER Havlíček, 1987

Type species

Spirifer nucula Barrande 1879; Motol Formation, Bohemia, upper Wenlock.

Rufispirifer nucula (Barrande, 1879)?

Fig. 18

Synonymy

Spirifer nucula Barrande, 1879: pl. 2, figs 1-2.

Rufispirifer nucula (Barrande, 1879); Strusz 2010b:106-108, figs 15-16, *cum syn.*

Material

CPC43812 to 43814, locality CC312; ANU33479A, Pillans locality 57.

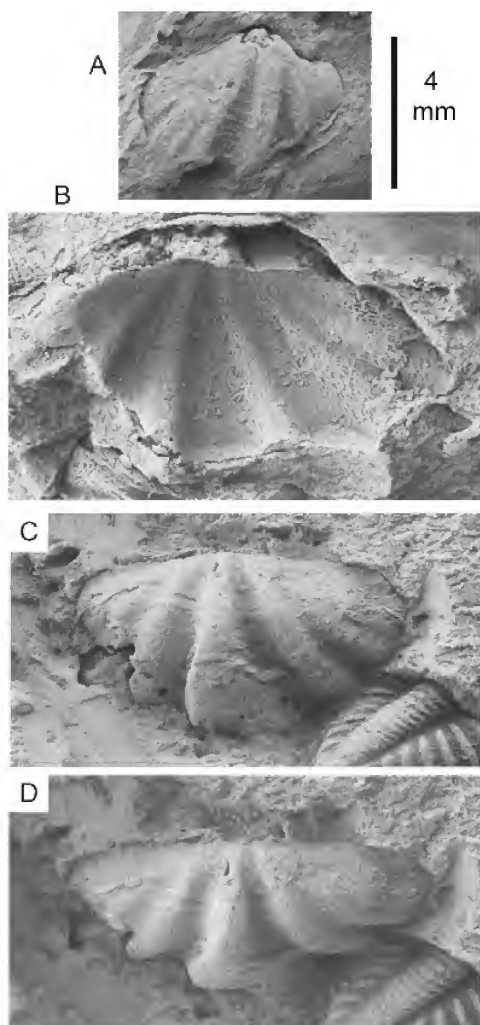


Figure 18. *Rufispirifer nucula?*. A, CPC43812, ventral valve internal mould; B, CPC43813, dorsal valve external mould showing fimbriate microornament; C-D, CPC43814, dorsal valve internal mould, tilted in D to show small bilobed cardinal process, lack of crural plates; locality CC312, Colinton Volcanics.

Description

The better preserved ventral valves have a well developed sulcus and flanking plications, a relatively wide hinge line (Wh/Ws about 0.8), prominent umbo, concave interarea with open triangular delthyrium flanked by narrow upright deltidial plates, and short

extrasinal dental plates. Dorsal valves are moderately convex with prominent fold, low umbo; the cardinal process appears to be bilobed (CPC43814, Fig. 18D), with each lobe longitudinally grooved; while other details of the cardinalia are more obscure, there is a low notothyrial platform but no crural plates. Microornament is capillate, of the delthyrid type described by Williams et al. (1997:342-345) and Strusz (1985), and so distinct from the eospiriferid type found in small *Hedeina*.

Remarks

While generally very poorly preserved, these small ribbed spiriferides are most likely to be the same species as occurs in the late Wenlock Yarralumla Formation of Canberra (Strusz 1984) and Bohemia (Havlíček and Štorch 1990), and the Ludlow of Molong (Strusz 2010b).

Suborder DELTHYRIDINA Ivanova, 1972
Superfamily RETICULARIOIDEA Waagen, 1883
Family RETICULARIIDAE Waagen, 1883
Subfamily RHENOTHYRIDINAE Gourvennec, 1994
Genus *SPIRINELLA* Johnston, 1941

Type species

Spirinella caecistriata Johnston, 1941;
Wenlock, Yass, New South Wales.

Diagnosis

‘Medium size; equidimensional to slightly transverse, smooth, inequivalve with apsacline, curved central interarea; cardinal angles rounded; fold and sulcus smooth, very low, poorly defined except near uniplicate commissure; flanks lacking plications, or with 1-3 weak plications flanking fold and sulcus anteromedially; numerous closely spaced growth lamellae with marginal spine bases or papillae; moderately long, divergent dental plates, short delthyrial plate or apical thickening, and variably impressed ventral muscle field; ctenophoridium and short posteriorly sessile crural plates.’ (Strusz 2010a:108).

Spirinella caecistriata Johnston, 1941
Fig. 19

Synonymy

Spirinella caecistriata Johnston, 1941:161-167, pl. VII, figs 1-11.
Spirinella caecistriata Johnston, 1941; Strusz 2011:45-46, fig. 12, *cum syn.*

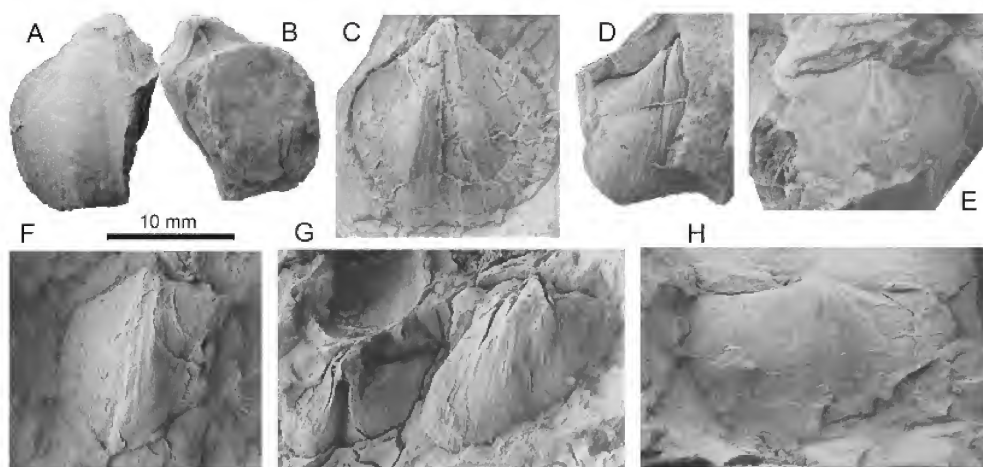


Figure 19. *Spirinella caecistriata*. A-B, CPC43833, incomplete ventral valve, viewed obliquely in B to show interarea; C, CPC43828, ventral valve internal mould; D, CPC43829, incomplete ventral valve internal mould; E, CPC43802, dorsal valve internal mould; F, CPC4380, ventral valve internal mould; G, CPC43803, two strongly distorted ventral valve internal moulds; H, CPC43834, dorsal valve internal mould. A-B, locality CC198, upper Cappanana Formation; C-D, locality BEG42, Rothlyn Formation; E-H, locality CC308, Cappanana Formation.

Holotype

AM F39376; Yass Formation, Homerian, Yass, NSW

Material

CPC43833, locality CC198; CPC43802-43804, 43834, locality CC308; CPC43828, 43829, locality BEG42.

Diagnosis

'Suboval, moderately ventribiconvex *Spirinella* with prominent ventral umbo, erect to slightly incurved beak; interarea concave, weakly apsacline, not well delineated laterally. Teeth small, triangular; dental plates long, moderately divergent, continued anteriorly by grooves of *vascula media*; ventral muscle field generally somewhat impressed, elongate, longer than dental plates; delthyrial plate or apical thickening small, crescentic; crural plates narrow, triangular, more or less convergent downwards, rest posteriorly on small notothyrial platform; lanceolate dorsal adductor field and myophragm.' (Strusz 2011:46).

Description

There is one incomplete, distorted, but otherwise reasonably well preserved ventral valve from locality

CC198, a very incomplete ventral internal mould from locality BEG42, and a jumbled assortment of mostly broken, strongly distorted internal and external moulds on one specimen from locality CC308. Despite the mostly poor preservation specific identity is certain.

The valve from CC198 is convex and of moderate size (Ls 15.6 mm, Ws est. 15 mm, hinge about 2/3 Ws), smooth, with a narrow, shallow sulcus, and microornament typical of the genus. The hinge line is fairly long, the cardinal angles are rounded, the interarea concave, the delthyrium open and flanked by narrow upright deltidial plates. There is a very small concave delthyrial plate beneath the apex of the delthyrium. The ventral internal mould from BEG42 has long, moderately divergent dental plates, and is comparable with CPC24875 from the Canberra Formation (Strusz 2010a:fig. 18O).

External moulds from CC308, while less well preserved, do show the general form and typical microornament of the genus. The best of the ventral internal moulds show long divergent dental plates and a faintly impressed muscle field whose outline is obscure. Dorsal internal moulds are poorer, but one shows a small bifid ctenophoridium such as seen on CPC24876 (Strusz 1985:fig. 14C-D) from the Canberra Formation - in fact the two valves are very similar, even to the degree of distortion.

SILURIAN BRACHIOPODS FROM BREDBO AREA, NSW

Remarks

The genus and species have been comprehensively analysed by Strusz (2010a:108-117).

ACKNOWLEDGEMENTS

This study is based on material collected in the nineteen sixties by parties of final-year undergraduate students working at the then Bureau of Mineral Resources, but has had to await analysis until the much better preserved faunas of the Yass Syncline had been fully studied. I would like to offer them, and the staff geologists who supervised them, belated thanks for their efforts. My thanks also to Natalie Schroeder of Geoscience Australia for her help in retrieving the collections, and likewise to Brad Pillans, Lynne Bean and Valerie Elder of the Research School of Earth Sciences, ANU, for making available Brad's honours thesis and specimens. Finally, I would like to thank David Barnes for photographing some very small and difficult specimens, and Ian Percival (New South Wales Geological Survey) for helping with that photography, and for his many useful comments on the manuscript. The work has been carried out in my capacity as School Visitor at ANU, and Research Associate of the Australian Museum, Sydney.

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SILURIAN BRACHIOPODS FROM BREDBO AREA, NSW

APPENDIX - LOCALITY LIST

The localities used in this study, and shown in Fig. 1, lie on the Bredbo 1:25 000 sheet 8726-3S (Geoscience Australia localities prefixed CC) and Murrumbucca 1:25 000 sheet 8725-4N (Geoscience Australia localities prefixed BEG), both 2016 editions. These localities were originally marked on 1959 air photos (held by Geoscience Australia library), and have been plotted on enlargements of these recent maps. Grid references to localities which were not used (CC191-197, 304-306, 309-311; BEG27, 34-37, 39-41) have been entered on the original locality cards. The two localities from which Pillans (1974) collected fossils have also been replotted on the new maps. Grid references in most cases are to the nearest 10 metres; in a few instances where streams, trees or roads have changed significantly the accuracy may be reduced to the nearest 50 metres. This list places the original field numbers in parentheses (as those are what is marked on the air photos and samples), and also gives the current stratigraphic position (after Henderson 1990), fossils recorded, and lithology.

CC188 (B24) Bredbo FA9903.1852; ca 200 m SSW of woolshed S of Bredbo-Jerangle road, in gully, a western tributary of Capanana Creek parallel to and S of access track to woolshed; Capanana Formation, mudstone fairly low in the formation. *Hedeina oepiki*, indet. rugosan, bivalve.

CC189 (B38, B38a) Bredbo FA9841.1946; in gully just S of Bredbo-Jerangle road; Capanana Formation, mudstone. *Mesoleptostrophia (Mesoleptostrophia) oepiki*, *Morinorhynchus cf. oepiki*, *Salopina medio-costata*, *Atrypa? sp.*, *Atrypoides (Atrypoides) australis*, *?Nucleospira paula*, *Navispira? cf. bicarinata*, *Nanattegia sp.*, *Hedeina oepiki*, *Janius bowningensis*, *Favosites*, heliolitid, syringoporid, alveolitid, *Rhizophylum interpunctatum*, syringaxonid? rugosan, *Tryplasma*, *Batocara*, *Oncopyge*, bryozoans, gastropods.

CC190 (B60) Bredbo FA9826.2142; on gully bank, about 1.5 km NW of Bredbo-Jerangle road; Capanana Formation, interbedded nodular silty limestone and siltstone close to the top of the formation. *Mesoleptostrophia (Mesoleptostrophia) oepiki*.

CC198 (point 6 in section between C30 and C37) Bredbo FA983.188; gully extending E from Connollys Gap to Capanana Creek, locality described as ca 40 m S of track to woolshed, ca 300 m SE of gate on Bredbo-Jerangle road; Capanana Formation, calculated from dips to be 860 m above the Ordovician, in the transition zone to the Colinton Formation; mudstone with calcareous nodules. *Atrypoides (Atrypoides) australis*, *Spirinella caecistriata*.

CC307 (D10b) Bredbo FA9827.2304; in Capanana Creek just N of track crossing; Capanana Formation, mudstone. *Eopholidostrophia (Megapholidostrophia) sp.*, *Morinorhynchus cf. oepiki*, *Hedeina oepiki*; *Phaulactis?*, *Batocara*, bryozoans.

CC308 (D21b) Bredbo FA9814.2266; near small gully, west of Capanana Creek about 750 m SE of woolshed N of Bredbo-Jerangle road; Capanana Formation, mudstone with interbedded limestone lens. *Spirinella caecistriata*.

CC312 (E4) Bredbo FA9783.1463; in gully 200 m NE of access road to 'Cappawidgee' farmhouse about 3.9 km from the turnoff on the Bredbo-Jerangle road; Colinton Volcanics, siltstone. *Epelidoaegiria minuta chilidifera*, *Janius bowningensis*, *Rufispirifer nucula?*; *Batocara*.

CC313 (E5) Bredbo FA9791.1465; in gully 315 m NE of 'Cappawidgee' access road about 3.9 km from turnoff on Bredbo-Jerangle road, 115 m above CC312; Colinton Volcanics, siltstone. *Rhynchotrema? sp.*, *Rufispirifer nucula?*

BEG38 (H13) Murrumbucca FA9882.1280; west side of track, about 1.5 km S of 'Cappawidgee' farmhouse; Capanana Formation 12 m below Colinton Volcanics, mudstone. *Morinorhynchus cf. oepiki*, *Atrypoides (Atrypoides) australis*, *?Hedeina oepiki*; *Batocara*.

BEG42 (J18) Murrumbucca FA9621.1272; just south of Billilngra Siding on abandoned Queanbeyan-Cooma railway; Rothlyn Formation, siltstone. *Mesoleptostrophia (Mesoleptostrophia) oepiki*, cf. *Clorinda sp.*, *Atrypa? sp.*, *Spirinella caecistriata*; *Batocara*.

Pillans 56 Murrumbucca FA9583.1312; gully about 70 m west of abandoned railway line, about 290 m north of Billilngra Siding; Rothlyn Formation, poorly sorted gritty tuffaceous mudstone. *Morinorhynchus cf. oepiki*.

Pillans 57 Murrumbucca FA9617.1308; gully about 470 m NW of Billilngra Siding on abandoned railway; Rothlyn Formation, fine pyritic sandstone. *Mesoleptostrophia (Mesoleptostrophia) oepiki*, *Rufispirifer nucula?*

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VOLUME 139



CONTENTS

Volume 139

Papers published in 2017, compiled 31 December 2017

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(date individual papers were published online at eScholarship)

Volume 139

Compiled 31 December 2017

TABLE OF CONTENTS

- | | |
|--------|---|
| 1-8 | Predator morphology and behaviour in <i>Branchinella occidentalis</i> (Dakin, 1914) (Branchiopoda: Anostraca: Thamnocephalidae).
D.C. Rogers and B.V. Timms. |
| 9-56 | Precis of Palaeozoic palaeontology in the southern tablelands region of New South Wales.
I.G. Percival and Y.Y. Zhen. |
| 57-67 | <i>Octopus kapalae</i> , sp. nov.: A new species of <i>Octopus</i> from south-eastern Australia
D.R. Mitchell and A. Reid. |
| 69-83 | Early Devonian conodonts from the southern Thomson Orogen and northern Lachlan Orogen in north-western New South Wales.
Y.Y. Zhen, R. Hegarty, I.G. Percival and J.W. Pickett. |
| 85-106 | Silurian brachiopods from the Bredbo area north of Cooma, New South Wales, Australia
D.L. Strusz |